REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
00/00/74

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
GEOLOGY OF GROUNDWATER RESOURCES IN COLORADO, AN INTRODUCTION

5. FUNDING NUMBERS

6. AUTHOR(S)
PEARL, R.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
COLORADO GEOLOGICAL SURVEY. DEPT. OF NATURAL RESOURCES
DENVER, CO

8. PERFORMING ORGANIZATION REPORT NUMBER
82314R01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

THIS REPORT DESCRIBES, IN SUMMARY FORM, THE GROUNDWATER RESOURCES OF COLORADO. ITS PURPOSE IS TO GIVE A NONTECHNICAL PRESENTATION OF FACTUAL INFORMATION ABOUT THE HYDROGEOLOGICAL CONDITIONS OF
COLORADO. THE GROUNDWATER RESOURCES OF COLORADO ARE DISCUSSED AND PRESENTED IN MAPS AND TABLES IN RELATION TO WATER QUANTITY, QUALITY, AND DISTRIBUTION AS RELATED TO THE VARIOUS GEOGRAPHIC REGIONS OF THE STATE.

14. SUBJECT TERMS
HYDROGEOLOGICAL CONDITIONS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

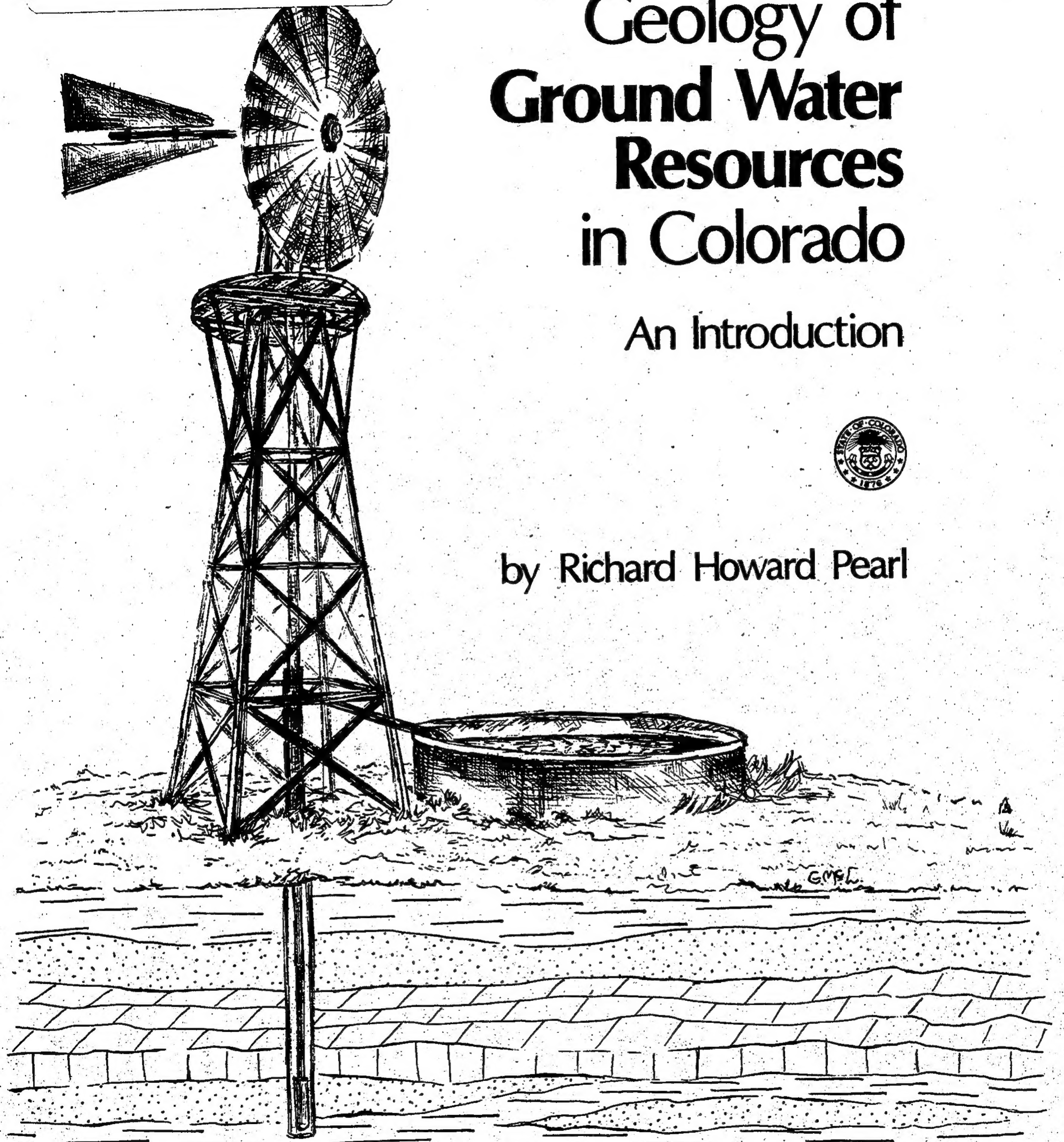
20. LIMITATION OF ABSTRACT

82314R01
Original

SPECIAL PUBLICATION 4

Geology of Ground Water Resources in Colorado

An Introduction



by Richard Howard Pearl

Colorado Geological Survey / Department of Natural Resources
Denver, Colorado / 1974 / Reprinted 1980

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SPECIAL PUBLICATION 4

GEOLOGY OF
GROUND WATER RESOURCES
IN COLORADO

An Introduction

by Richard Howard Pearl

Colorado Geological Survey
Department of Natural Resources
State of Colorado
Denver, Colorado

1974

Reprinted 1980

$3.00

Cover by: Genevieve Ladwig

Illustrations by: Robert G. Gast

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INTRODUCTION

This report describes, in summary form, the ground-water resources of Colorado. Its purpose is to give a nontechnical presentation of factual information about the hydrogeological conditions of Colorado. The ground-water resources of Colorado are discussed and presented in maps and tables in relation to water quantity, quality, and distribution as related to the various geographic regions of the State.

Due to over appropriation of surface-water supplies and rapid urban growth in many areas of Colorado which do not have adequate surface-water supplies, more and more usage is being made of ground-water in the state. Thus, Colorado's ground-water resources are becoming increasingly important with their development continuing at a fast pace.

ACKNOWLEDGMENTS

The author, in preparing this paper, drew heavily upon the published reports and data presented at the end of the paper. For those interested in learning more about the hydrogeological conditions of Colorado than herein presented, they are referred to this list.

GROUND-WATER RESOURCES

Ground-water, the water naturally occurring below the surface of the ground, may be obtained from springs or from pumped or flowing wells which are dug, driven, or bored into consolidated rocks or loose sand and gravel. Ground water is found almost everywhere throughout the world to a depth of more than 2 miles below the surface of the earth. The source of this water was precipitation, which infiltrated the ground and percolated downward through the earth to the water table.

Climate and topography determines the amount of water available to streams and for ground-water recharge. The mean annual precipitation in Colorado is approximately 16 inches and ranges from approximately 6.5 inches at Alamosa in the San Luis Valley, to more than 50 inches in some of the high mountain areas. An average of 90 million acre-feet (one acre-foot of water equals 1 acre, 1 foot deep and contains 325,900 gallons) falls annually as precipitation in Colorado. A large part of this is lost by evapotranspiration, with about 16 million acre-feet appearing as runoff in the major streams.

Ground-water occurs under two different conditions, artesian or water table (Fig. 1). Artesian conditions develop when an inclined saturated water-bearing formation (aquifer) is bounded on the top by an impermeable formation. Depending upon the extent of saturation when a well is drilled into this type of aquifer, the water will either flow to the surface (a flowing artesian well) or rise in the well-bore (artesian well). Water-table conditions occur whenever the aquifer is not bounded by an impermeable formation, such as in unconsolidated sands and gravels (alluvium) found along and adjacent to rivers and streams. When a well is drilled into this type of aquifer, water will only fill the well bore to the level of the water in the surrounding aquifer.

Some of the seemingly solid rock formations have voids called pores (Fig. 4) in which ground-water is stored. If enough of these pores are interconnected, the porous rock is called permeable and is able to transmit water, and the water-bearing rock is an aquifer. Normally, the movement of ground-water through these rocks is very slow, on the order of only a few feet to a few hundred feet per year.

Unlike sedimentary rocks, crystalline igneous (granites, pegmatite dikes, etc.) and metamorphic rocks (schists and gneisses) are so dense that voids, in which sufficient quantities of water can be stored, normally do not exist between the mineral grains. Unlike most sedimentary rocks, crystalline rocks are normally broken by numerous faults and joints--openings into which water flows and collects.

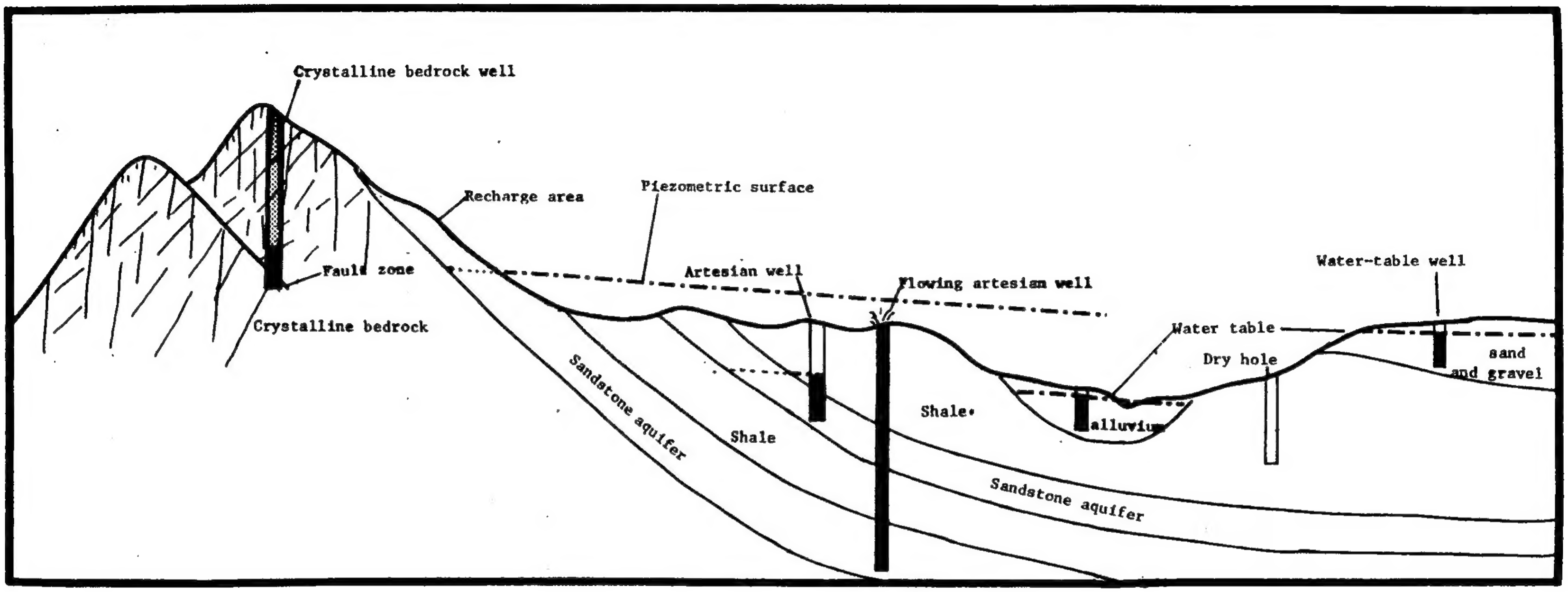

Figure 1. Cross section illustrating ground-water conditions of Colorado.

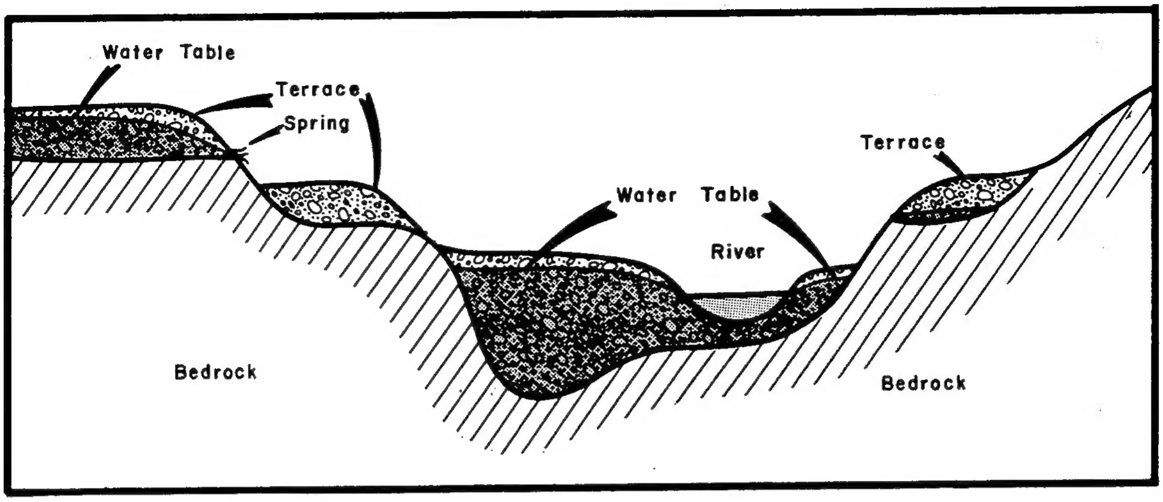

Figure 2. Diagrammatic cross section through an unconsolidated alluvial and terrace aquifer system found along most major rivers.

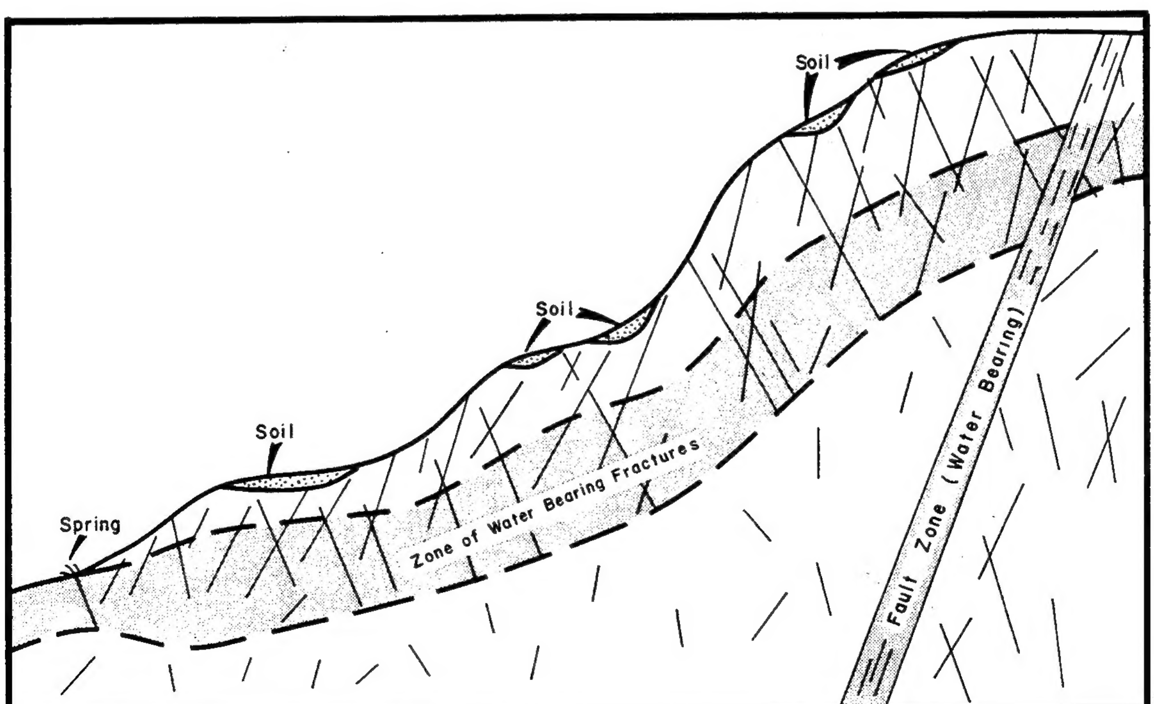

Figure 3. Diagrammatic cross section through a fractured crystalline bed rock aquifer system showing relationship between geologic conditions and occurrence of ground water.

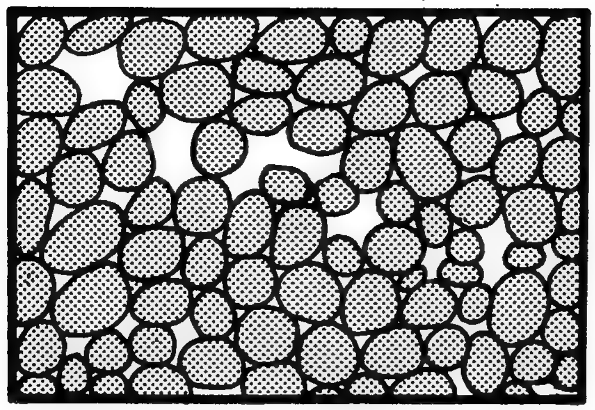

Figure 4 Example of porosity and rock texture

When a well is drilled into these rocks, one or more joints or faults may be encountered which contain some ground water (Figs. 1 and 3).

Throughout most of Colorado, buried rock formations extend outward in all directions from basin centers, rising gradually until they outcrop along the basin margins, which in Colorado is usually along mountain fronts. Sometimes these formations may extend up over the mountain cores. As shown on Figure 1 these outcrop regions are areas of recharge where precipitation falling on the surface begins its downward movement to the ground-water reservoir.

The sedimentary rock layers in these basins are thousands of feet thick. As an example, in the San Luis Valley, the sedimentary rock layers are approximately 30,000 feet thick. Considering the thousands of cubic miles of rock formations present, the total amount of available ground-water in storage in Colorado is extremely large. However, the amount of ground-water present in any one locality is strongly influenced by such geological factors as: nature of the material at the earth's surface, whether it is permeable or impermeable; permeability of the aquifer; and, structural configuration of the rocks.

Ground water supplies are available in most of Colorado, particularly adjacent to the major streams, in the mountain basins, the

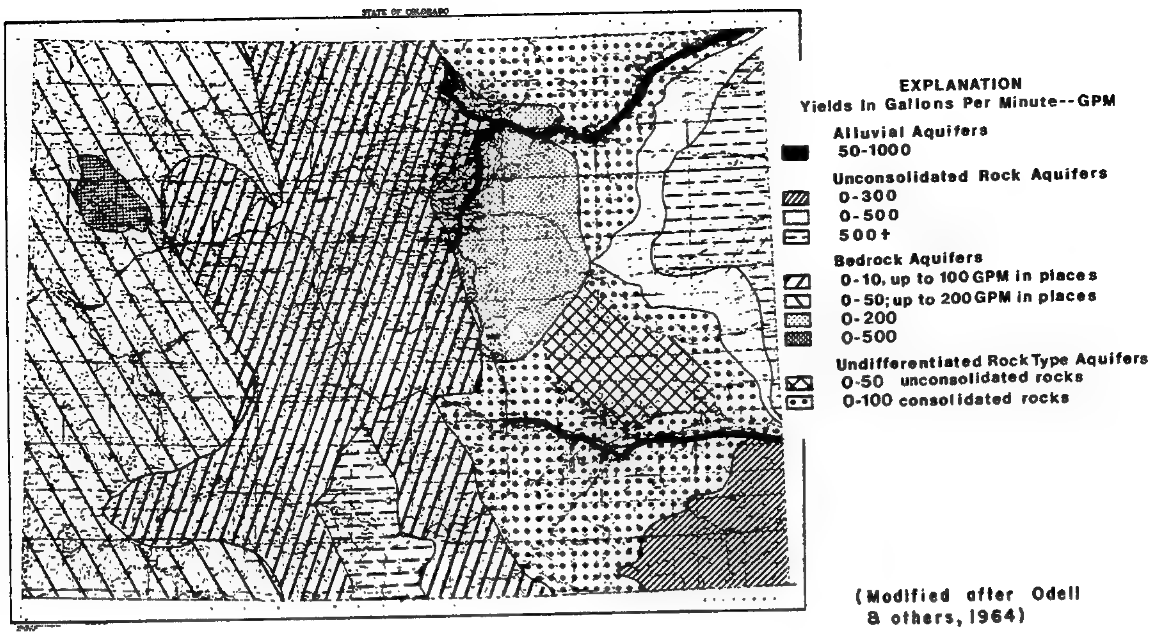

Figure 5. Water well yield potential map

High Plains of eastern Colorado, and in other areas underlain by extensive aquifers. In the mountain and plateau regions of western Colorado, ground-water supplies are generally limited (see Fig. 5 for general availability of ground water in Colorado).

The majority of Colorado's ground-water resources occur east of the Continental Divide, in contrast to the surface water supplies of which two-thirds occurs in the Colorado River basin of western Colorado. Much of the ground-water that is pumped in Colorado occurs in those areas that have the smallest surface-water supply. For instance, only about one-quarter of the State's surface-water supply occurs in the three river basins (South Platte, Arkansas, and Rio Grande) in which most of the ground water is pumped.

The aquifers in Colorado yielding the largest amounts of ground water are largely unconsolidated alluvial sand and gravel deposits. The principal aquifers of this type in eastern Colorado include deposits in the San Luis Valley, the Ogallala Formation of the High Plains, and the valley-fill deposits in the Rio Grande, Platte, and the Arkansas river valleys . West of the Continental Divide, a few stretches of valley-fill deposits along the principal streams are aquifers, but in general, the largest aquifers in western Colorado

are the various sandstone units. Where tapped by wells, the Leadville Limestone yields large quantities of water which normally contains large amounts of dissolved solids.

GROUND-WATER QUALITY

The chemical quality of a ground-water supply is a variable that must be considered in any evaluation of the supply. According to U.S. Public Health standards (1962), water for human consumption should have not more than 1,000 miligrams per litre (mg/l--milligrams per litre are equivalent to parts per million--ppm) total dissolved solids (TDS) and preferably no more than 500 mg/l. However, many people in Colorado, particularly those in the lower Arkansas River valley, use ground water with TDS concentrations greater than 1000 mg/l. Even though the ground-water contains mineral matter above recommended concentrations, it is used because a better source is not available. Its use also continues because people have become accustomed to drinking the concentrated water. Livestock can use water of higher TDS concentrations than humans can. An upper limit of 5,000 mg/l is recommended by some investigators for livestock consumption.

Water quality requirements for industrial purposes range widely For some industrial uses, the quality is not particularly critical and water of almost any quality may be used. At the other extreme are the processes which require water approaching the quality of distilled water. However in general, water which meets standards for domestic use is usually suitable for most industrial uses.

Items that need to be considered in evaluating ground water supplies for irrigation are TDS, concentrations of certain constituents (such as boron), the amount of sodium present, and the sodium content relative to the calcium and magnesium content. Before any ground-water supplies are developed and used for irrigation, the local agricultural agencies should be contacted concerning the suitability of the water in relation to the soil and crop to be irrigated.

TABLE I - CLASSIFICATIONS OF WATER

(Sources: Todd, D. K., The water encyclopedia, Water Information Center.)

A. Based on Concentration of Total Dissolved Solids

Name	Concentration of Total Dissolved Solids, parts per million
Fresh	0-1000
Brackish	1000-10,000
Salty	10,000-100,000
Brine	More than 100,000

B. Based on Hardness

Name	Hardness as $CaCO_3$, parts per million
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	More than 180

Hard water is caused principally by high concentrations of calcium and magnesium in the water. Ground-water in the alluvial aquifers generally is moderately hard to very hard. In consolidated aquifers, it is soft to very hard, with extreme variations occurring in the same aquifer.

GROUND-WATER RESOURCES OF COLORADO

For purposes of this paper, the ground-water conditions of Colorado are described by river basins. These basins are (Fig. 6): The South Platte River basin which includes the Northern High Plains and the North Platte River basin; the Arkansas River basin and the Southern High Plains; the Rio Grande River basin; Western

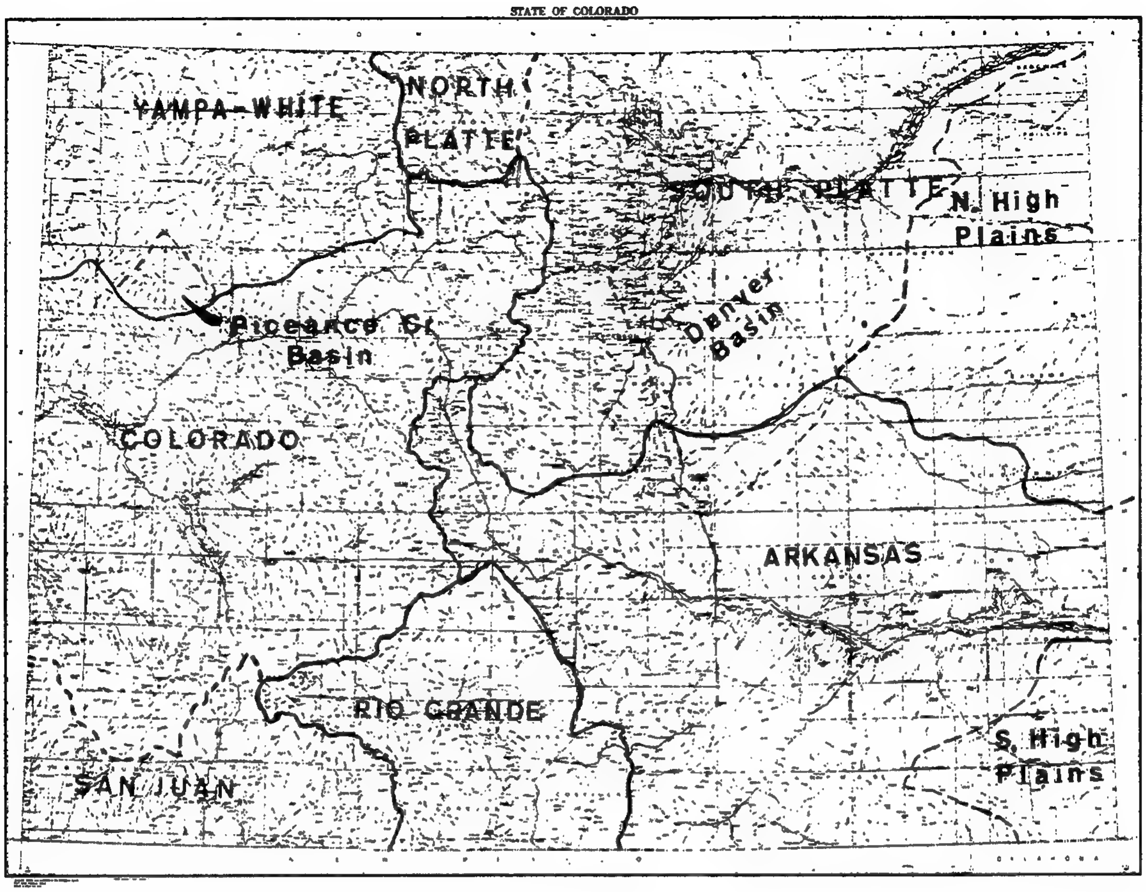

Figure 6. River basins of Colorado

Colorado which includes the San Juan River basin; the Colorado River; and Yampa-White River basins. The areas of Colorado having the greatest present and potential ground-water development are in the first three basins. Large supplies of ground-water possibly could be developed from the valley-fill deposits occurring along short stretches in the other river basins of western Colorado and from the Piceance Creek structural basin in Northwestern Colorado.

EASTERN COLORADO

That part of Colorado east of the Continental Divide and drained by the South Platte and Arkansas River systems can be divided into two very dissimilar areas having distinct and different hydrological

regimes. One area, the High Plains of extreme eastern Colorado, is an area that receives very little precipitation, and unlike other areas of the state, no rivers cross it that head in the mountains. As a result, this area has very little surface-water supplies available for use and the ground-water resources have been extensively developed. The area north of the Arkansas River and south of the South Platte River, the northern High Plains, is drained by the Republican-Arikaree River and Smoky Hill River systems. The area south of the Arkansas River, the southern High Plains, is drained by the Cimarron River system.

The other area of eastern Colorado, consisting of high mountains on the west and plains on the east, is drained by the South Platte on the north and Arkansas River on the south, both of which head in the mountains. Due to availability of surface-water supplies, these supplies over the years have been extensively developed and, in some cases, recently have been supplemented with ground-water supplies.

SOUTH PLATTE RIVER BASIN

Introduction

The South Platte River basin includes all of the northeastern one-fourth of Colorado, with the exception of the Northern High Plains and the North Platte River basin which will be discussed separately (Fig. 7). The river basin is comprised of two very dissimilar regions--mountains and plains. The western part of the basin contains high, rugged mountains while the eastern plains area is an area of low relief and low precipitation. Due to favorable geological conditions and an abundant supply, extensive use is made of ground-water throughout much of the basin.

Two important sub-basins, South Park and the Denver Basin, are part of the South Platte River basin. Recent land developments in these two basins in the last few years has caused increased usage of ground water to occur.

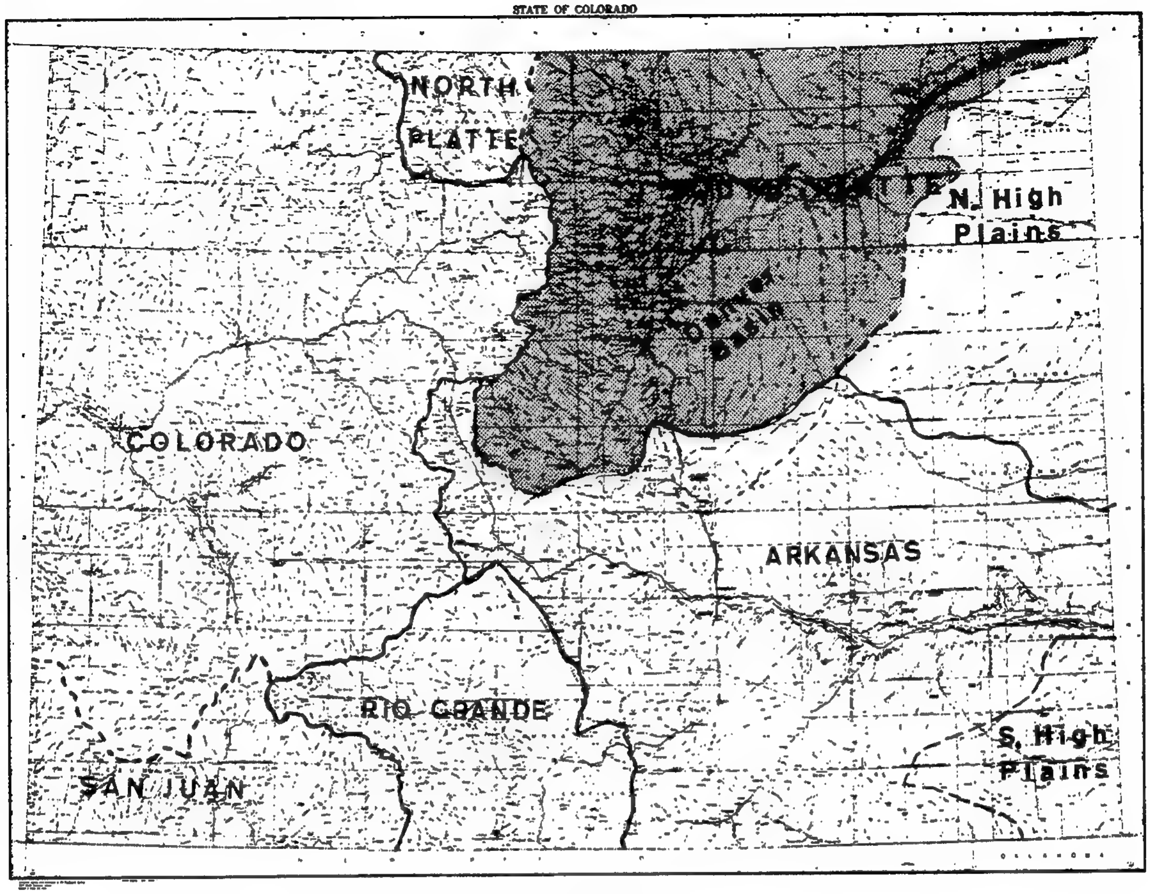

Figure 7. South Platte River basin

GEOLOGY

Precambrian age rocks are exposed throughout the mountainous western part of the South Platte River basin area. These rocks, which have been cut by numerous faults and joints, consist of metamorphic schists and gneisses intruded by igneous rocks.

East of the mountains, underlying the Plains, are over 18,000 feet of sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age (Table 2). However, due to deposition, erosion, and structural control, nowhere in the basin is this total thickness of sedimentary rocks present in any one place. Along the mountain front, these formations have been structurally folded and faulted and are generally steeply dipping while a few miles to the east they are flat lying to gently inclined.

Table 2.-- Summary of ground-water resources of the northeastern one-fourth of Colorado.

System	Series	Formation	Thickness (feet)	Physical Character	Water-Supply
Quaternary	Holocene	Dune sand	0-100	Sand, silt, and clay, unconsolidated	Yields only small amounts of water to wells.
	Pleistocene	Alluvium	0-300	Gravel, sand, silt and clay, lenticular and unconsolidated.	Important source of water along the river valleys. Supplies large quantities of water to irrigation and public supply wells.
		Terrace deposits.	0-130	Sand and gravel, with some cemented zones.	Yields moderate to large quantities of fair to poor quality water to irrigation and domestic wells.
		Upland deposits	0-100	Gravel, sand, silt and clay may be locally cemented.	Locally may yield small to moderate amounts to water to wells.
	Pliocene	Ogallala	0-400+	Gravel, sand, silt, and clay, with some interbedded cemented calcareous sandstone and limestone. Does not extend any further west than Limon, Colorado.	Important source of water on the High Plains. Yields large quantities of water to irrigation and municipal wells.
	Miocene	Arikaree	0-80	Sandstone. Present only in extreme northeast Colorado.	May yield small quantities of water to stock and domestic wells.
Tertiary	Oligocene	White River Group. (Brule Fm. at top, Chadron Fm. at base).	0-600	Silt with fine sand and clay. Some channel deposits of sand and gravel	Generally not an important source of water. Brule Fm. locally yields a moderate amount of water from porous and jointed zones. Chadron Fm. may locally yield small amounts of water to wells.
	Paleocene	Dawson Arkose: Denver Fm.	Total thickness 0-2,800'	Clay, shale and siltstone, with sandstone and conglomerate. Locally contains beds of volcanic ash and bentonitic clay.	Yields small to moderate amounts of water to domestic and stock wells.
		Dawson Arkose: Arapahoe Fm.		Sandy to clayey shale and clay with a few beds of sandstone. Lower part contains sand, gravel and conglomerate.	Yields small to moderate amounts of water to domestic and stock wells.
Cretaceous	Upper Cretaceous	Laramie	0-200+	Sand, clay, shale and sandstone. Contains coal.	Yields small to moderate amounts of water to stock and domestic wells. Quality varies locally.
		Fox Hills	0-200+	Shaley sandstone and sandstone.	Important source of water in the Denver Basin.
		Pierre	2,500-6,500	Shale and silt. Contains some sandstone lenses.	Not an important source of water. Locally may yield small to moderate amount of water to wells (quality usually not very good.)
		Niobrara	300	Marl shale in upper part. Lower 20' consists of dense limestone	Not an important source of water. Fractured limestone locally will yield small amounts of poor quality water.
		Benton	500	Shale	Not an important source of water. Locally may yield small quantities of poor quality water.
	Lower Cretaceous	Dakota	300+	Sandstone and shale	Yields small to moderate amounts of water. Usually has high iron content.
Jurassic	Upper Jurassic	Morrison	300	Sandstone, marlstone, limestone, mudstone, and locally gypsum beds.	Not an important source of water. Sandstone beds might contain small amounts of water. Quality would be questionable.
		Ralston Cr.	120	Claystone, limestone, and siltstone.	Not an important source of water. Might contain small amounts of highly mineralized water.
Triassic? and Permian.		Lykins	400	Sandstone and shale with some thin limestone.	Not an important source of water.
Permian		Lyons	200	Sandstone	Yields small to moderate amounts of water.
Pennsylvanian		Fountain	1,100	Conglomeratic sandstone, mudstone, and shale.	Yields small quantities of water locally.
Precambrian				Igneous and metamorphic rocks of the mountains.	Locally yields very small to moderate amounts of water to domestic and stock wells from fractured and faulted zones. Quality is usually good but locally may be highly mineralized.

Source of data: U.S. Geological Survey Water-Supply Papers number 1378, 1539-T, 1658, 1669-X, 1777, 1809, 1819-I

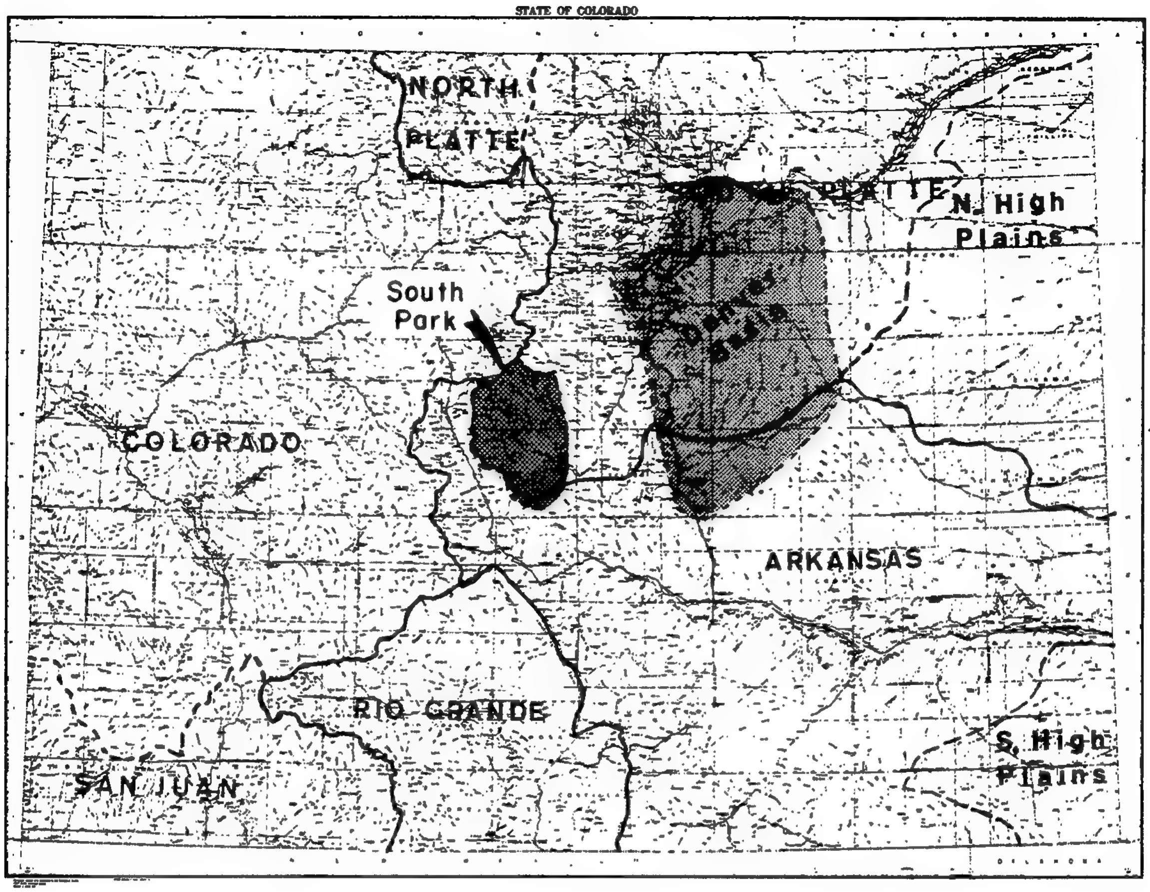

Figure 8. Denver Basin

Within the South Platte River drainage basin are two major structural basins: South Park and the Denver Basin. South Park (Fig. 8). a high intermountain basin, is located approximately 50 miles southwest of Denver. The basin is bounded on three sides by high rugged mountains and on the south by igneous lava flows. Rocks ranging in age from Precambrian to late Tertiary age are exposed in various parts of South Park. Along the margins of the basin, these rocks are found under varying structural conditions while in the central part of the Park, the rocks are essentially flat lying although locally they may be deformed.

The Denver Basin (Fig. 8), located east of the mountains, stretches from near Colorado Springs on the south to near Greeley on the north, and to the western edge of the northern high Plains on the east.

The Denver Basin is asymmetrical in shape, with the west side being very steeply inclined while the east side is gently inclined. For example, rocks exposed at the surface along the mountain front a few miles west of Denver are found at a depth of 15,000 feet under Denver. Some of the formations exposed along the west side of the basin do not crop out along the east side.

HYDROGEOLOGICAL CONDITIONS

It has been estimated that there may be as much as 130 million acre feet of recoverable ground-water in storage in the South Platte River basin. Of this amount, approximately 4 million acre-feet occurs in the alluvium of the South Platte River east of the mountains and 100 million acre feet occurs in the bedrock aquifers of the Denver Basin (J. C. Romero, oral communication, 1974).

Most of the rocks in the basin are to some degree water bearing. However, due to the large size of the basin and varying structural conditionsfound within the basin, the amounts of water yielded from any one aquifer will vary locally and can vary considerably within a short distance. Some of the more important aquifers in the South Platte River basin are: alluvial and terrace deposits found along the courses of the major rivers and streams; Dawson Arkose; Laramie-Fox Hills sandstone, and the Precambrian crystalline rocks. The alluvial deposits found along, and immediately adjacent to the major rivers and streams and the alluvial terrace deposits bordering at a slight elevation above the major rivers are probably the most important aquifers in the South Platte basin. These deposits, up to 300 feet thick, consist generally of un-cemented, interbedded gravels, sands, silts and clays. The quality of the water contained in the alluvial deposits will vary greatly throughout the basin due to either upstream usage or the nature of the bedrock occuring under the alluvium. Well yields of up to 1,000 gpm (gallons per minute) or more are common from the alluvial aquifers.

The White River Group, consisting of two formations, the Brule Formation at the top and the Chadron Formation at the base, is a locally important source of water. Yields as much as 1,400 gpm have

been reported from the Brule Formation, but they are not common.

The Dawson arkose, and its lateral equivalents the Denver and Arapahoe Formations, are probably the most important sedimentary bedrock aquifers in the basin. This formation, which is up to 2,800 feet in thickness, occupies the central portion of the Denver Basin. Consequently, with the increased urbanization of the Denver Basin, most domestic wells obtain their water from this unit. Well yields up to 200 gpm can be expected from this aquifer.

The Denver Formation, equivalent to the upper part of the Dawson Arkose, usually yields less than 50 gpm of water to wells. The underlying Arapahoe Formation yields small to moderate (average of 100 gpm) amounts of water to wells.

The other important bedrock aquifer in the South Platte River basin is the Laramie-Fox Hills aquifer. This is a very important aquifer, especially in the eastern part of the Denver Basin. This aquifer, which consists of cemented sandstone, yields varying amounts of water to wells. Wells that fully penetrate the aquifer yield approximately 100 gpm, and a few yield as much as 600 gpm.

The crystalline igneous and metamorphic rocks of the mountains yield small to moderate amounts of water to wells. Wells tapping this aquifer are usually capable of yielding 10 gallons per minute or less. However, if a fault zone is tapped larger yields may be expected.

The ground-water contained in the consolidated bedrock aquifers of the South Platte basin is usually of fairly good quality with the dissolved solids being less than 500 mg/l. The exception to this is where the ground-water has come into contact with the Pierre shale or the coal beds of the Laramie Formation. These two formations contain an abundance of readily soluble minerals which, when dissolved in the water, have a deleterious effect on water quality.

The sedimentary bedrock formations of Cretaceous and Tertiary age exposed east of the mountains normally contain abundant quantities of soluble minerals. Most of the area east of the mountains has a semi-arid climate; therefore, very little runoff is produced. However,

the land underlain by these formations is some of the most extensively irrigated land in Colorado. The effect of irrigation return flow coupled with the low precipitation, plus effects of man upstream, causes a downstream change in the quality of the South Platte River. The South Platte River at the edge of the mountains at Waterton, Colorado, had a dissolved solids concentration of less than 100 mg/1. The dissolved mineral matter in the mountain streams is usually calcium bicarbonate. Further downstream the South Platte near Greeley, Colorado, contains an average of 1,000 mg/1 of dissolved solids with the main constituents being sodium, calcium, sulfate and bicarbonate. At Julesburg, Colorado, at the Nebraska - Colorado State Line, the concentrations of dissolved solids has increased to 1,200 mg/1.

NORTHERN HIGH PLAINS

INTRODUCTION

The northern High Plains of eastern Colorado (Fig. 9) is drained by the Republican-Arikaree, and Smoky Hill rivers. Like the southern High Plains and unlike most of the other river basins of eastern Colorado no streams cross the northern High Plains which head in the mountains. The two river systems which drain the basin head some 70 miles east of the mountains and approximately 100 miles west of the Colorado-Kansas State Line. The small volume of surface water in these streams has restricted its use as compared to surface water use in other Colorado basins.

GEOLOGY

The principal aquifer underlying the northern High Plains is the Ogallala Formation of Pliocene age (Table 2). The Ogallala Formation consists of cemented to uncemented clays, silts, sands, and gravels which generally becomes coarser and less cemented in the lower part of the formation. The Ogallala Formation thickens eastward from a thickness of a few feet at its western edge to about 400 feet in thickness north of Wray. Local variations in thickness are due to irregularity in the underlying bedrock surface (Figs. 10 and 11).

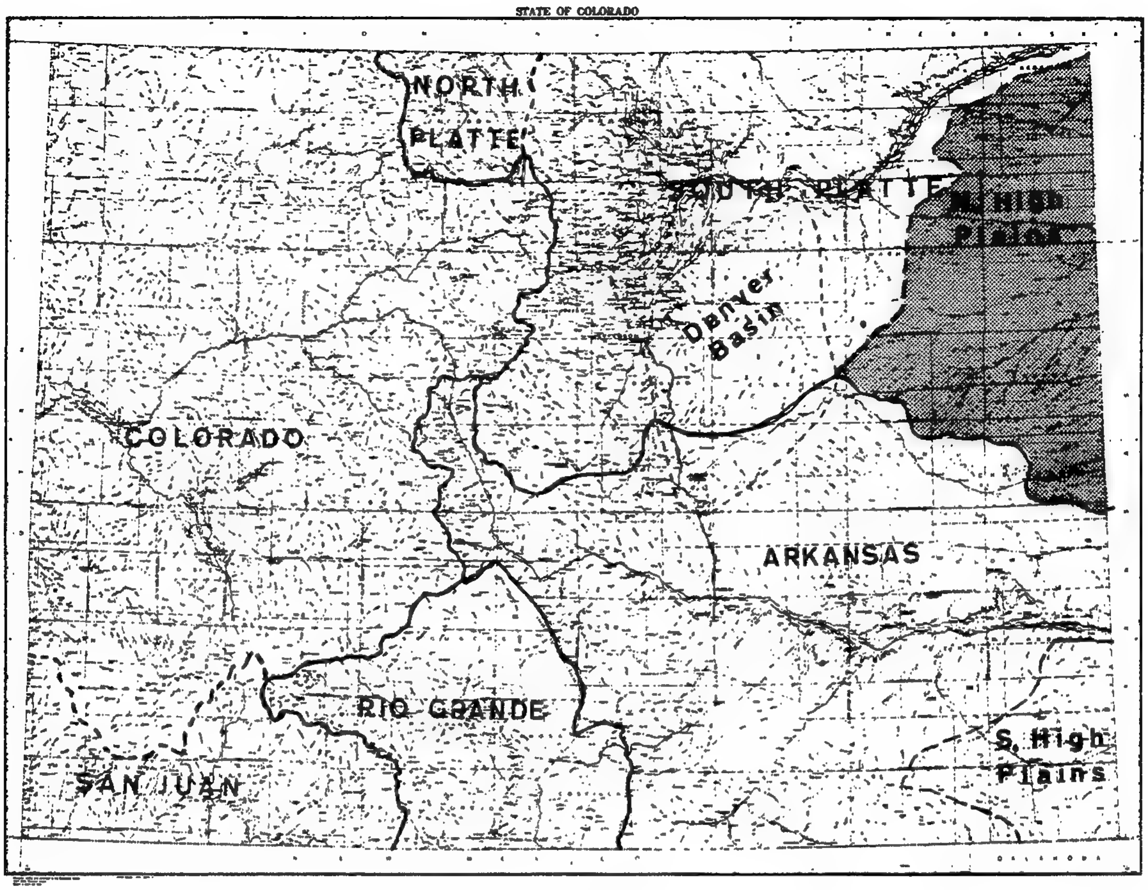

Figure 9. Northern High Plains

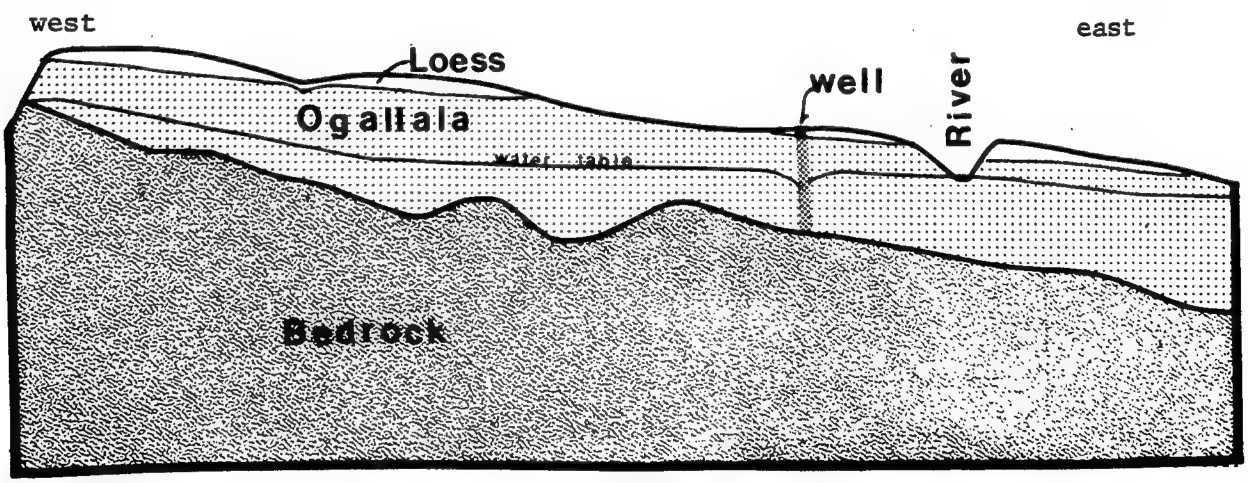

Figure 10. Diagrammatic east-west cross section through northern High Plains (Adapted from Hofstra and others, 1972)

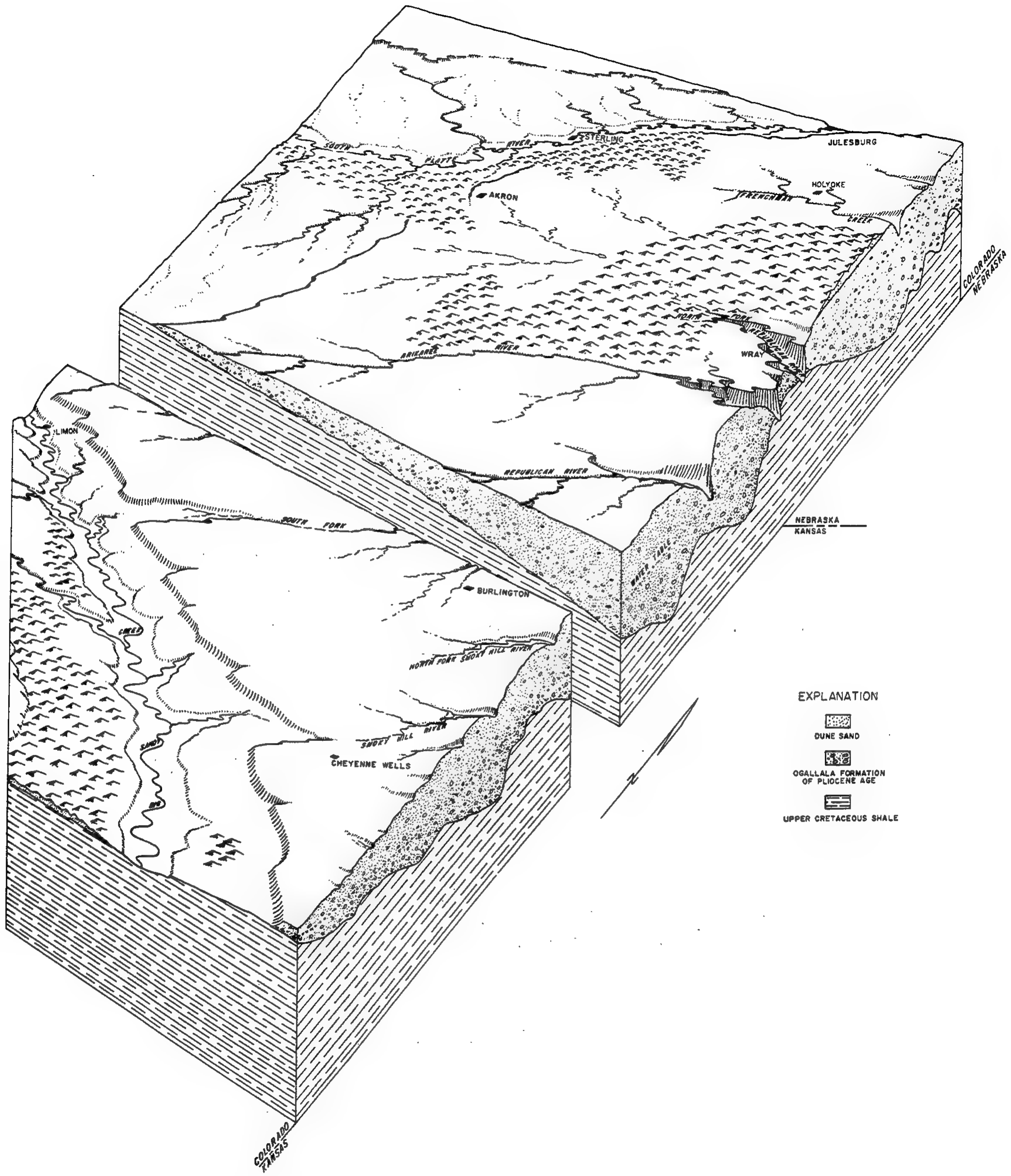

Figure 11. Block diagram of the northern part of the Colorado High Plains (From Hofstra and others, 1972)

Other formations controlling the occurrence of ground water in the area are the Pierre shale, White River group, alluvium, loess and dune sand. The shale and siltstone of the Pierre shale and White River group that underlie the Ogallala Formation form an almost impermeable barrier to the downward movement of water. The alluvium and dune sand which overlie the Ogallala Formation are sufficiently permeable to absorb large amounts of precipitation and allow it to migrate downward to the water table. The alluvial deposits occur as channel deposits along the streams. Dune sand which overlies the Ogallala Formation, ranges in thickness from a few inches to approximately 100 feet.

HYDROGEOLOGICAL CONDITIONS

Most ground-water in the northern High Plains occurs in the Ogallala Formation under water-table conditions. Approximately 80 million acre-feet of recoverable ground water are stored in this aquifer. Configuration of the water table indicates that the ground-water moves in a general eastward direction into Kansas and Nebraska. The thickness of the saturated material ranges from a few feet along the west side of the area to about 350 feet in the eastern part.

Yields of wells in the northern High Plains range from a few gallons per minute to about 2,000 gallons per minute. In general, only in those areas where the saturated thickness is greater than 50 feet can wells yield sufficient quantities of water for irrigation (greater than 500 gpm).

The water in the Ogallala aquifer is generally suitable for domestic and irrigation purposes with concentrations of dissolved solids ranging from 100 to 500 mg/l. The best quality water is found in the northern part of the area where dune sand overlies the aquifer and the saturated thickness is greater than in other parts of the northern High Plain. Water of poorer quality is found along the western edge and in the southern part of the area, where saturation is limited and the formation is underlain by shales of the Niobrara Formation.

Due to limited recharge, and large agricultural irrigation demands,

the water table is falling within the Ogallala aquifer. Declines of over 16 feet have been reported in the Burlington area for the period 1964-71.

NORTH PLATTE RIVER BASIN

INTRODUCTION

The North Platte River basin of north-central Colorado (Fig. 12) is bounded on the east by the Front Range, which consists of the Medicine Bow and Never Summer Mountains, on the west by the Park Range, on the South by the Rabbit Ears Range, and on the north by the Colorado-Wyoming state line. The basin acually consist of two basins--the North Platte and Laramie Rivers. The Medicine Bow Mountains separates the two basins. As their geology and hydrology is quite similar they will here be discussed as one basin.

GEOLOGY

Precambrian age rocks and rocks ranging in age from Permian to Holocene are exposed throughout the basin. The Precambrian age rocks, which are exposed in the central parts of the mountain uplifts, consist of metamorphic schists and gneisses extensively intruded by granitic igneous rocks. Overlying these rocks are more than 19,000 feet of sedimentary rocks ranging in age from Permian to Holocene. However, due to erosion, deposition, and structural control, this total thickness is not everywhere present.

North Park is a large synclinal trough formed between mountain ranges. As a result of the extensive mountain building that has occurred, the sedimentary rocks in the basin are found under all types of structural control. These rocks are extensively folded and faulted and are anywhere from nearly flat-lying to very steeply dipping.

HYDROGEOLOGICAL CONDITIONS

Due to the generally steeply dipping nature of the bedrock

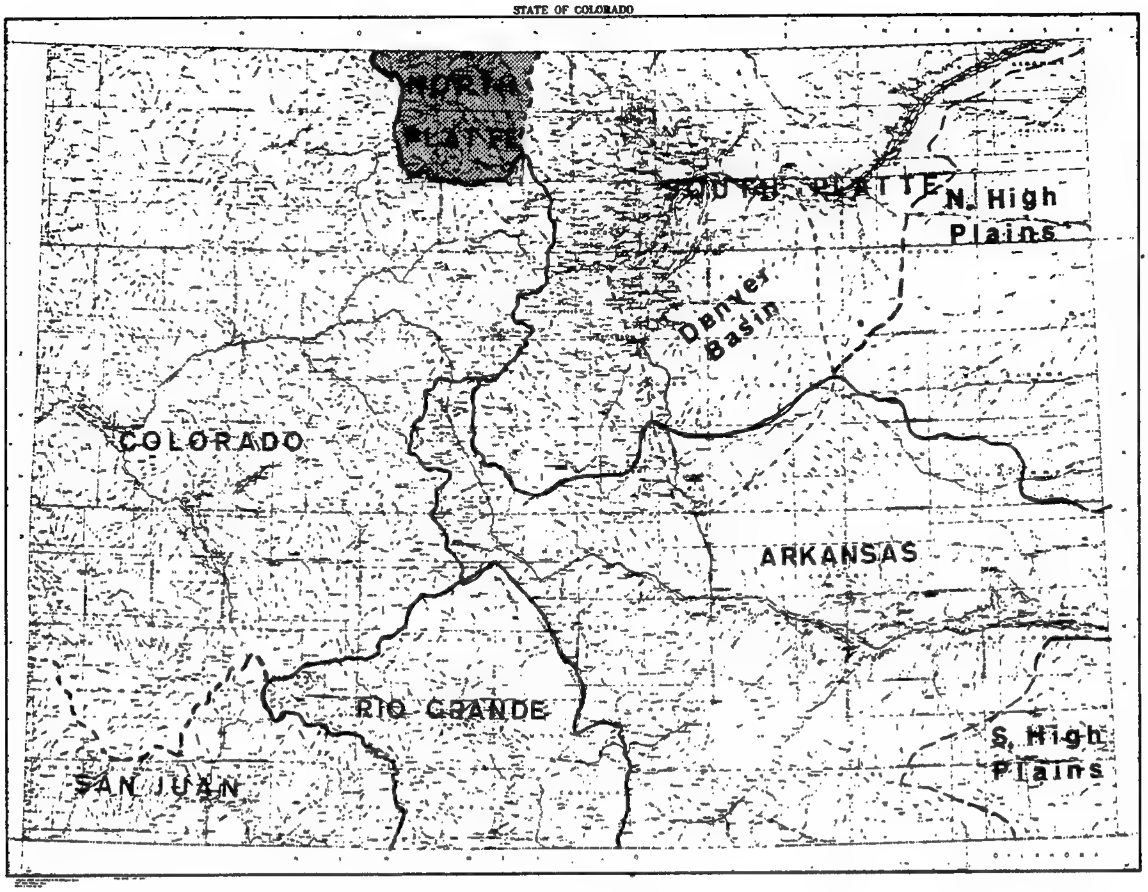

Figure 12. North Platte River basin

formations and the structural deformation of these rocks along the margin of the basin ground-water surfaces will usually only be obtained within a short distance of the outcrop.

Some of the more important aquifers in the North Platte basin in descending order are (Table 3): valley-fill alluvium, North Park Formation, Coalmont Formation and Precambrian crystalline rocks. The Dakota sandstone, Sundance Formation may yield small quantities of water to wells within a short distance of the outcrop, however, normally they are found at depths too great.

Valley fill alluvium is found along most of the river and stream courses within the basin. These deposits consisting of sand, gravel, clay and silt up to 80 feet in thickness yield

Table 3.--Summary of ground-water resources of North Park.

System	Series	Formation	Thickness (feet)	Physical Character	Water-Supply
Quaternary	Holocene	Alluvium	0-80+	Unconsolidated sand, gravel, silt and clay.	Important source of water. Yields adequate amounts for domestic and stock uses.
	Pleistocene	Terrace deposits	0-6	Sand and gravel	Locally yields water to springs and seeps
		Glacial deposits	0-150	Sand, gravel, clay and boulders	Yields adequate amounts of water to domestic and stock wells.
		Continental deposits (undifferentiated)	0-400	sandstone, conglomerate, shale siltstone, and claystone	Yields small amounts of water to springs and seeps.
Tertiary		Intrusive and extrusive rocks		Igneous rocks	Not known to yield water to wells. Might yield small to moderate amounts of water.
	Miocene	North Park (Troublesome)	0-2,000	sandstone and conglomerate with some siltstone, clay, volcanic ash and tuff.	Yields small to moderate amounts of water to wells.
	Eocene and Paleocene	Coalmont	6,000-9,000	Sandstone, shale, coal and conglomerate. Equivalent in part to Middle Park Fm.	Locally yields good quality water for stock and domestic purposes. Locally may be of poor quality.
Cretaceous	Upper Cretaceous	Pierre	3,000-4,500	Shale with thin beds of sandstone.	Does not yield water.
		Niobrara	400-900	Shale with thin beds of limestone.	Does not yield water.
		Benton	500-650	Shale, sandstone and thin limestone beds.	Does not yield water.
	Lower Cretaceous	Dakota	165-320	Sandstone and conglomerate with some shale beds.	Not an important source, but may yield some water to wells.
Jurassic		Morrison	400-500	Shale and marl, with thin layers of limestone and sandstone.	Does not yield water.
		Sundance?	100-150	Sandstone with some siltstone and limestone beds.	May yield water locally, but usually buried at great depth.
Triassic and Permian		Chugwater	600-800	shale and sandstone.	Does not yield water to wells
Permian		Santanka	0-50	Shale	Does not yield water to wells.
Precambrian				Igneous and metamorphic rocks.	Locally yields water of good quality to wells and springs.

Source of data: U.S.Geological Survey Water-Supply Paper No. 1809-G

adequate quantities of water of generally good quality to domestic and stock wells.

The North Park Formation, up to 2,000 feet thick of calcareous sandstones with some siltstone, clay, volcanic ash and tuff yields water to wells in the northwestern and central parts of North Park. Reported well yields of wells tapping this aquifer are not large, usually less than 50 gpm.

The Coalmont Formation, 6,000-9,000 feet in thickness is found throughout the central part of the North Park. This formation consists of sandstone, shale, conglomerate, and coal beds. Yields of wells tapping this aquifer again are not large; less than 10 gpm with the quality of the water varying. If the coal beds which are within the formation are not cased off, the water quality could become degraded.

Precambrian age crystalline rocks found in the central parts of the mountain ranges are an important local source of water. Depending upon whether just fractures are encountered, or if fault zones are encountered by the well, the yield of the well will range from a low of less than 1 gpm up to 100 gpm. Water obtained from these rocks is usually of good quality.

ARKANSAS RIVER BASIN

INTRODUCTION

The Arkansas River basin of eastern Colorado comprises almost the entire southeastern one-fourth of the State with the exception of the southern High Plains area (Fig. 13). Like the South Platte River basin to the north, the Arkansas River basin is composed of two distinct physiographic regions. The western one-third of the basin is composed of mountains while the eastern two-thirds is plains.

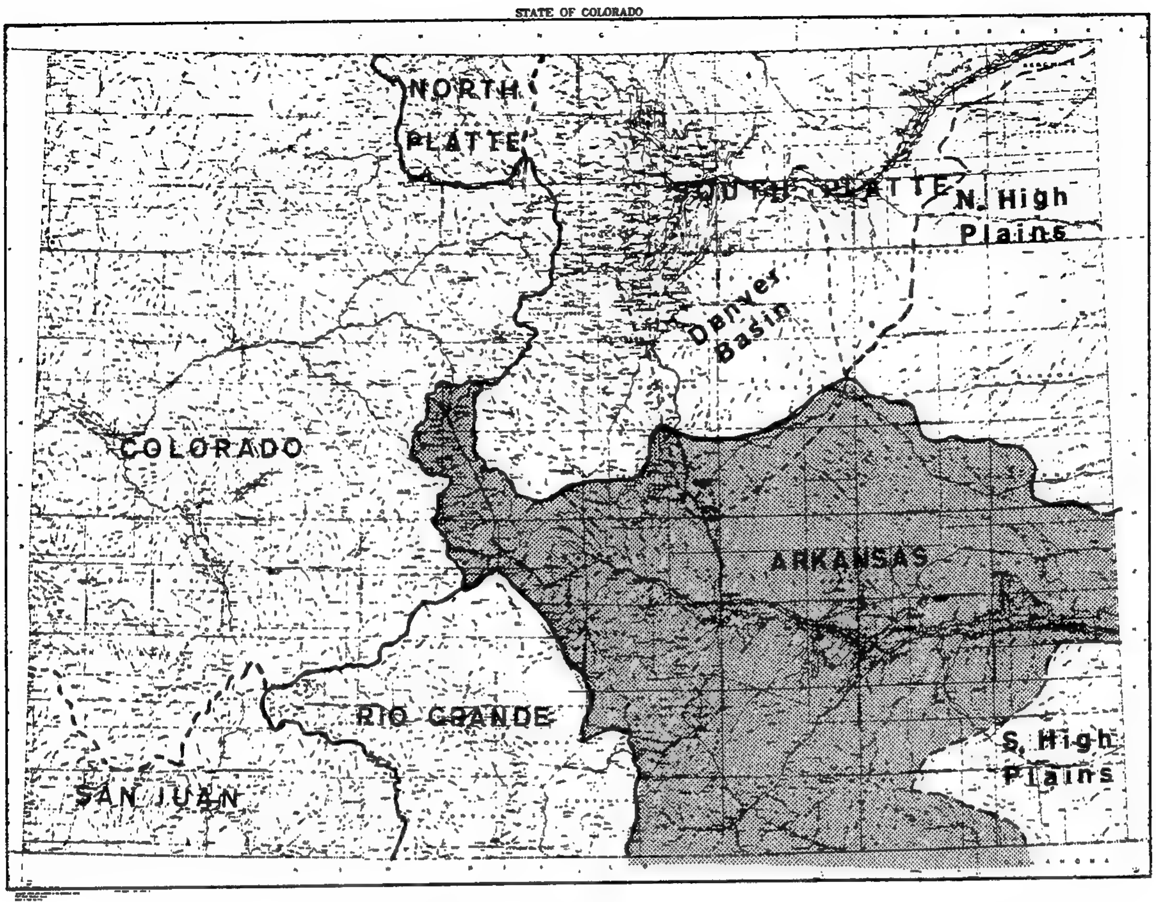

Figure 13. Arkansas River basin

GEOLOGY

Rocks ranging in age from Precambrian to Recent are exposed throughout the basin, and are found under all types of structural control. The Precambrian age rocks, which generally are exposed in the central parts of the mountain up-lifts, consist of metamorphic schists and gneisses extensively intruded by igneous rocks. Overlying these rocks are more than 10,000 feet of sedimentary rocks of Paleozoic, Mesozoic, and Cenozoic age. Due to deposition, erosion, and structural control, nowhere in the basin is this total thickness of sedimentary rocks present in any one place. As a result of the large size of the basin and the complex geology it is possible for the same rock unit to be known by various names in different parts of the basin. Therefore, no attempt will be made here to list the various formations. For a complete

description of the formation in the Arkansas River basin see Table 4.

HYDROGEOLOGICAL CONDITIONS

Due to numerous factors such as, unfavorable hydrogeological conditions, lack of demand, and lower land use developmental pressures, smaller amounts of ground-water supplies are used in the Arkansas River Valley than in the South Platte River basin. It has been estimated that there may be as much as 30 million acre-feet of recoverable ground water located in the Arkansas River basin.

In the mountainous parts of the basin the principal aquifers are the crystalline bedrock and the valley fill alluvium. Small amounts of water are obtained from the limited sedimentary rocks present in the mountainous region of the basin. The crystalline rock aquifers will yield small to moderate (usually 10 gallons per minute or less) amounts of water to wells.

East of the mountains the principal aquifer is the valley fill deposits found along the Arkansas River and some of its large tributaries like Fountain Creek, the Purgatory River, and Big Sandy Creek. Yields of wells tapping the alluvial aquifer along the Arkansas River average 800 gallons per minute.

Varying quantities of ground-water are obtained from the sedimentary bedrock formations which occur in the river basin, especially in the area south of the Arkansas River. Water in the bedrock formations, south of the Arkansas River, which is under artesian pressure, is used mainly for domestic and municipal supplies. The main artesian aquifers in that area are: The Cheyenne sandstone member of the Purgatory Formation, and the Dakota sandstone. As these same formations are found at great depths north of the Arkansas River, very few wells are drilled to them in that area.

As a result of the two distinct topographic areas of the basin, the geologic conditions have a very pronounced influence on water quality. The upper part of the basin is a mountainous region with complex geologic conditions which limit the exposure of the rocks to water.

Table 4.-- Summary of ground-water resources of southeastern one-fourth of Colorado (From Elbert-El Paso County line on north to Colo.-New Mexico state line on south, Continental Divide and crest of Sangre De Cristo-Culebra Mnts. on west to Colo.-Kansas state line on east).

System	Series	Formation	Thickness (feet)	Physical Character	Water-Supply
Quaternary	Holocene	Dune sand	0-50	Unconsolidated sand with some silt and clay.	Locally may yield small amounts of water to domestic and stock wells.
		Alluvium	0-30	Unconsolidated sand, silt and gravel.	Yields adequate amounts of water for domestic and stock use.
	Pleistocene.	Terrace deposits	0-25	Unconsolidated sand, silt, gravel, cobbles and small boulders.	Usually lies above the water table and does not yield water to wells.
Tertiary		Extrusive rocks		Basalt and other igneous rocks. Forms lava flows.	Does not yield water to wells.
		Intrusive rocks		Basalt and other igneous rocks.	Does not yield water to wells.
	Pliocene	Ogallala	0-400	Sand, gravel, silt with some cemented sandstone lenses.	Important source of water north of Arkansas River and inparts of Prowers and Baca Counties.
	Miocene?	Devils Hole	0-1,300	Tuff and conglomerate	Yields water to wells and springs in Huerfano Park.
	Oligocene?	Farisita	0-1,200	Conglomerate and sandstone	Yields water to wells and springs in Huerfano Park.
	Eocene	Huerfano	0-2,000	Shale, sandstone and conglomerate	Yields small amounts of water to wells and springs locally.
Tertiary	Eocene	Cuchara	0-5,000	Sandstone and shale	Locally yields small amounts of water to wells.
	Paleocene	Poison Canyon	2,500	Sandstone and conglomerate with some shale and siltstone. Equivalent to part of Dawson Fm. of Colo. Springs area.	Locally yields small amounts of water to wells in southern part of area. Important source of water in Colo. Springs area.
		Raton	500	sandstone, shale, siltstone, and coal. Equivalent of the Dawson Fm. of the Colo. Springs area.	Yields small amounts of water to wells and moderate to large quantities to mines and mine shafts. Important source of water in Colo. Springs area.
Cretaceous	Upper Cretaceous	Vermejo	400+	Sandstone, siltstone, shale and coal. Equivalent to part of Laramie Fm. of the Colo. Springs area.	Yields small quantities of water to wells and springs. Quality may vary locally.
		Trinidad	300+	Sandstone. Equivalent to part of Fox Hills Fm. of the Colo. Springs area.	Yields small to moderate amounts of water to wells.
		Pierre	5,000±	Shale with some interbedded sandstone lenses.	Not an important source of water. Locally may yield small amounts of very poor quality water to wells.
		Niobrara: Smoky Hill	700+	Chalky and sandy shale.	Not an important source of water.
		Niobrara: Fort Hays	70	Limestone	Locally yields small quantities of water to wells. Not an important source of water.
		Carlile	290±	Shale with some sandstone lenses.	Generally does not yield water to wells. Codell sandstone member may yield small quantities locally.
		Greenhorn	120+	Limestone	Not an important source of water. Locally may yield small quantities of water to wells.
		Graneros	235±	Shale, with some thin limestone beds.	Generally does not yield water to wells.
	Lower Cretaceous	Dakota	150±	Sandstone with some shale	Yields adequate quantities of water for domestic and stock use. In some areas yields enough for municipal and industrial use.
		Cheyenne Sandstone: Purgatoire Member	225	Shale and sandstone.	Shale member (Kiowa shale) does not yield water to wells. Sandstone member (Cheyenne sandstone) yield small to large quantities of water to wells.
Jurassic		Morrison	325	Marl, sandstone, conglomerate and limestone.	Does not yield water to wells.
		Entrada	380	Sandstone.	Locally yields small quantities of water to wells.
Permian and Pennsylvanian		Sangre de Cristo	3,000	Sandstone, conglomerate, limestone and shale.	Yields water to springs and seeps, generally in mountainous areas.
		unnamed	5,000+	Conglomerate, sandstone, limestone and shale.	Yields water to springs in mountains.
Precambrian				Igneous and Metamorphic	Yields water to springs in mountains.

Source of data: U.S. Geological Survey Water-Supply Papers 1256, 1583, 1669-P, 1772, 1779-N, and 1805 and Professional Paper 551.

This area is also primarily composed of those rock types--igneous, metamorphic, and sandstones--which are generally more insoluble. Therefore, the streams draining them usually have a low concentration of dissolved solids. At the eastern edge of the mountains, at Canon City, the Arkansas River normally contains less than 200 mg/l of dissolved solids.

East of Canon City the geologic conditions are very different than those to the west. This part of the basin is underlain by nearly flat-lying Cretaceous, Tertiary and Quaternary age sedimentary rocks such as limestone, shale, sandstone and siltstone. These rocks are much more soluble, and contain larger amounts of more soluble minerals than those rocks found in the mountains. As these rocks have not been as structurally deformed as their counterpart in the mountains, their total surface area exposed to solution is greater. Consequently, the concentrations of dissolved-solids in both surface and ground waters increase progressively downstream with a dramatic increase in the amounts of magnesium, sodium, and sulfate. At Pueblo, Colorado, some 39 miles east of Canon City, the Arkansas River contains 500-600 mg/l of dissolved solids with the water being a calcium-sulfate, bicarbonate type. East of Pueblo the works of man, coupled with the geologic conditions has a great influence on the water quality. Most of the irrigation in the basin is east of Pueblo on land underlain by nearly flat-lying rocks. As a result, irrigation return flow, coupled with high evaporation rates, causes the concentration of dissolved solids in the river to increase dramatically downstream. Below John Martin Reservoir the river contains from 1500 mg/l to over 2,000 mg/l of dissolved solids. At the Colorado-Kansas State Line the dissolved-solids in the river has gone up to 3,000 mg/l and the water is a calcium sulfate type.

In the area south of the Arkansas River from Pueblo to the state line, large volumes of ground-water are pumped from the Dakota sandstone. Locally this water has a high radioactive level.

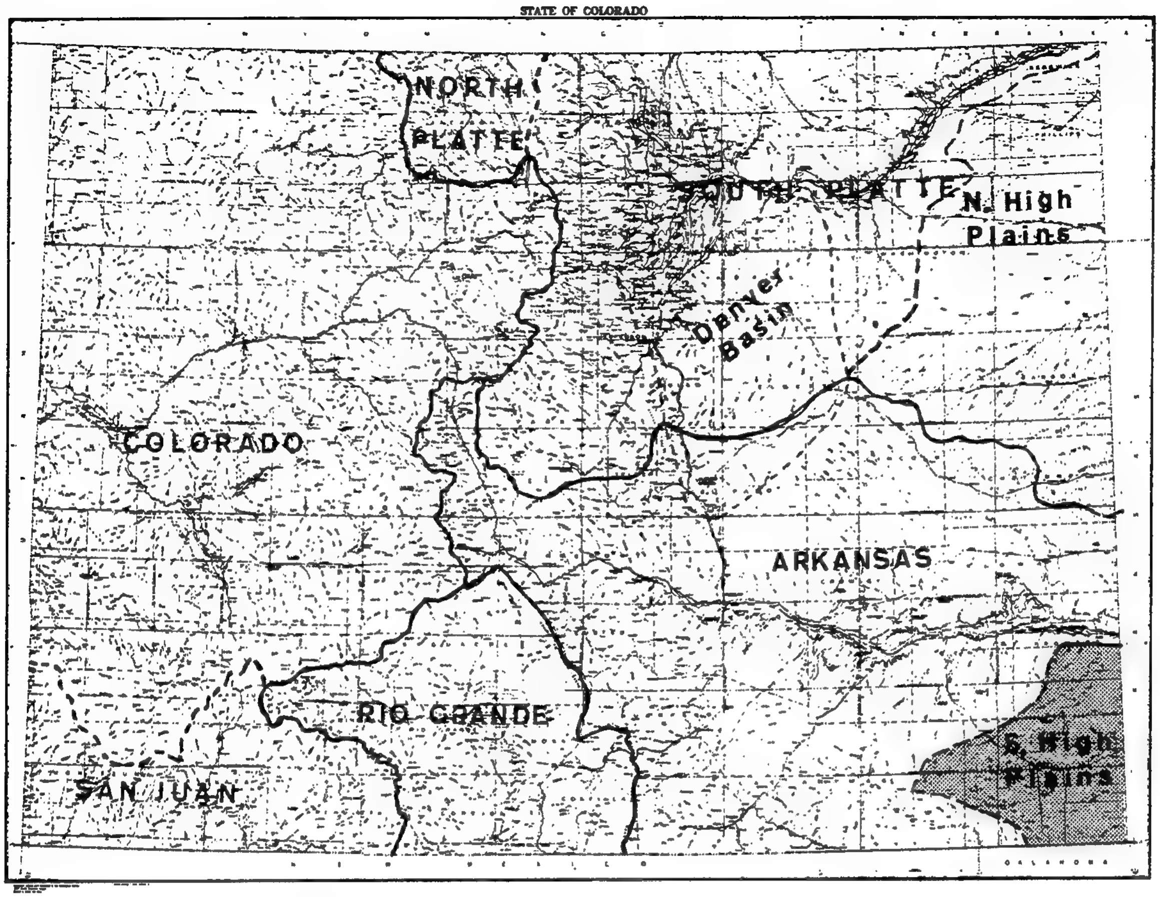

Figure 14. Southern High Plains

SOUTHERN HIGH PLAINS (CIMARRON RIVER BASIN)

INTRODUCTION

The southern High Plains of southeastern Colorado lie mostly within the Cimarron River Basin (Fig. 14). Southeastern Colorado is an area of low precipitation, 14-16 inches per year; consequently, very little surface water is available for industrial, municipal, domestic or irrigation purposes. In 1970, 130,000 acre-feet were pumped for irrigation purposes (J. E. Moore, oral presentation). It has been estimated that by 1977, 205,500 acre-feet of ground-water/year will be pumped for irrigation in the southern High Plains.

GEOLOGY

While most of the exposed rocks in the southern High Plains are of sedimentary origin, there are some rocks of igneous origin. The exposed sedimentary rocks, which consist primarily of sandstone and some limestone, range in age from Permian to Quaternary. The igneous rocks are of Tertiary age. For a description of these formations, see Table 4.

There are two pronounced geologic features in and adjacent to the Cimarron River basin: the Las Animas Arch and the Two Buttes intrusion. The Cimarron River basin is located on the east flank of the northeast trending Las Animas Arch. The Two Buttes intrusion is located north of Springfield, Colorado, along the north boundary of the Basin. While these two features may locally affect the dip of the bedrock formations, the sedimentary rock formations overall are generally gently dipping to the east into Kansas.

HYDROGEOLOGICAL CONDITIONS

The deeply eroded canyons in the western part of the area, along with the Las Animas Arch and the Two Buttes intrusion, isolate the aquifers from the surrounding areas, thus making the limits of the aquifers generally conform to the surface drainage area limits. The minor faulting found in the basin has only a limited effect on the ground-water regime.

Three water-bearing formations underlie nearly the entire area. They are: the Ogallala Formation, the Dakota sandstone, and the Cheyenne sandstone. These three formations contain approximately 8 million acre-feet of recoverable ground-water in storage.

The waters found in the three major aquifers are generally a calcium bicarbonate type with the amounts of dissolved-solids varying within an aquifer from locality to locality, with no apparent pattern. The total dissolved solid content of the waters in the Ogallala Formation ranges from 220 to 1,000 mg/l, in the Dakota sandstone and the Cheyenne sandstone they range from 140 to 1,900 mg/l.

As there are no formations underlying the area that contain large amounts of readily soluble minerals, like the Pierre shale, the quality of the irrigation return flow has a very limited affect on water quality in the streams.

Waters in the Dakota sandstone in other areas of southeastern Colorado are known to have a high level of radioactivity. However, no radiometric analysis of the waters in the Dakota sandstone in the Southern High Plains has been made.

RIO GRANDE RIVER BASIN

INTRODUCTION

The Rio Grande River basin of southcentral Colorado (Fig. 15) comprises approximately 7,700 square miles. The basin is bounded by the Sangre De Cristo Mountains on the east and northeast, the Continental Divide and San Juan mountains on the northwest and west and the San Luis Valley in the center.

The San Luis Valley is the most pronounced hydrological feature of the river basin. The valley is almost 100 miles long, and 50 miles wide, and has an area of almost 3,200 square miles. The valley floor, with the exception of the San Luis hills in the southern part, is nearly flat. Most of the valley floor is bordered by alluvial fans, the most extensive being the Rio Grande fan. This fan, which extends about 30 miles along the west side of the valley also extends about 20 miles eastward into the valley.

GEOLOGY

The San Luis Valley is a northern extension of the Rio Grande rift zone that stretches from Texas thru New Mexico to Colorado. The bedrock floor of the basin is asymmetrical in shape with the east side of the basin a down-dropped fault zone. Geophysical work by Colorado School of Mines students has shown that the valley bedrock floor may be as much as 30,000 feet deep in the vicinity of the

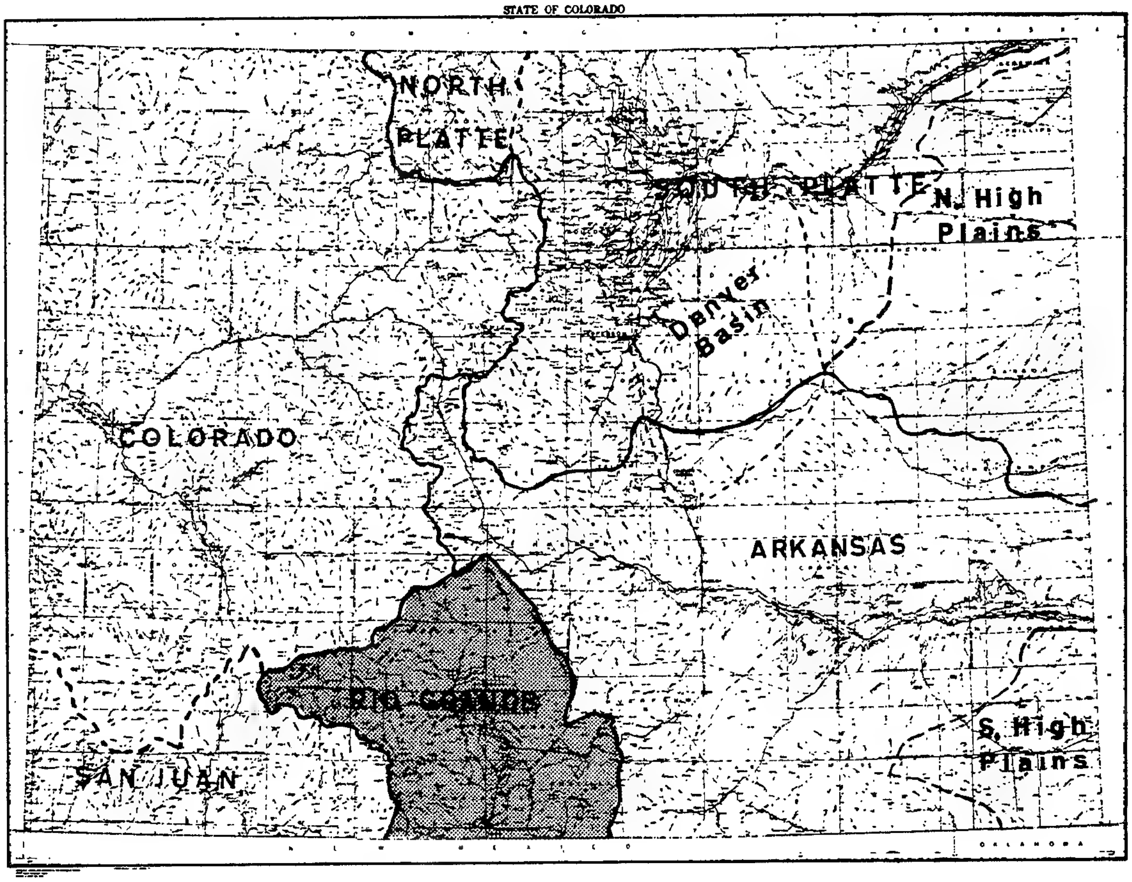

Figure 15. Rio Grande River basin

Mineral Hot Springs. Many of the volcanic rocks found on the west side of the valley extend eastward out into and dip under the floor of the San Luis Valley.

Rocks of various geologic ages are exposed throughout the Rio Grande River basin. Precambrian age crystalline rocks--granites, gneisses, and schists are found in the Sangre de Cristo Mountains. A thin section of Paleozoic age sedimentary rocks are present and are exposed along the north and east side of the San Luis Valley, these rocks have been divided into the following formations: Manitou limestone, Harding sandstone, Fremont Limestone, Chaffee Formation, Kerber Formation, Minturn Formation, and Sangre De Cristo Formation. The lower part of the sequence, the carbonate rocks, are restricted to the northeast part of the San Luis Valley, and do not extend any further

south than Crestone, Colorado. The western part of the basin is composed of volcanic flows, tuffs, and breccias of Tertiary to Holocene (Recent) age.

The San Luis Valley is primarily composed of Tertiary age sedimentary rocks nearly 30,000 feet thick interbedded inpart with lava flows (Fig. 16). Earlier workers correlated these rocks with several geologic formations in New Mexico. However, due to difficulty of correlation, these rocks are now classified as undivided.

HYDROGEOLOGICAL CONDITIONS

The San Luis Valley is estimated to contain over 2 billion acre-feet of ground water in storage with over 140 million acre-feet estimated to be recoverable. This is by far the greatest concentration of ground-water in the State. The consolidated sedimentary rocks found along the northern edge of the valley are not known to yield water to wells (Table 5).

Geophysical and drillers sample logs indicate that a clay series 10-80 feet thick exists throughout much of the central and northern parts of the valley at depths ranging from 50 to 130 feet below the land surface. These clay beds restrict the vertical movement of ground water and divides the valley into two aquifer systems, an upper unconfined aquifer and a lower confined aquifer. Shallow unconfined ground

Table 5.-- Summary of ground-water resources of Rio Grande River basin.

<table>
<tr><th>System</th><th>Series</th><th colspan="2">Formation</th><th>Thickness (feet)</th><th>Physical Character</th><th>Water-Supply</th></tr>
<tr><td rowspan="3">Quaternary and Tertiary</td><td rowspan="2">Holocene to Oligocene</td><td rowspan="2">Valley Fill</td><td>Unconfined aquifer</td><td>0-200</td><td>Clay, silt, sand and gravel, unconsolidated</td><td>Yields large amounts of water to well in San Luis Valley.</td></tr>
<tr><td>Confined aquifer</td><td>50-30,000</td><td>Clay, silt, sand and gravel, unconsolidated. Interbedded with lava flows and tuffs.</td><td>Yields large amounts of water to wells in San Luis Valley.</td></tr>
<tr><td>Oligocene</td><td colspan="2">Undivided</td><td>0-30,000 net</td><td>Volcanic rocks</td><td>Locally may yield small to moderate quantities of water to wells. Not an important source of water.</td></tr>
<tr><td>Paleozoic</td><td></td><td colspan="2">Undivided</td><td></td><td>Sandstone, limestone and shale.</td><td>Not an important source of water.</td></tr>
<tr><td>Pre-cambrian</td><td colspan="4"></td><td>Igneous and metamorphic rocks of the mountains.</td><td>Not an important source of water. May yield small amounts of water to wells in mountains surrounding San Luis Valley.</td></tr>
</table>

Source of data: Colorado Water Conservation Board Basic-Data Release No. 22.

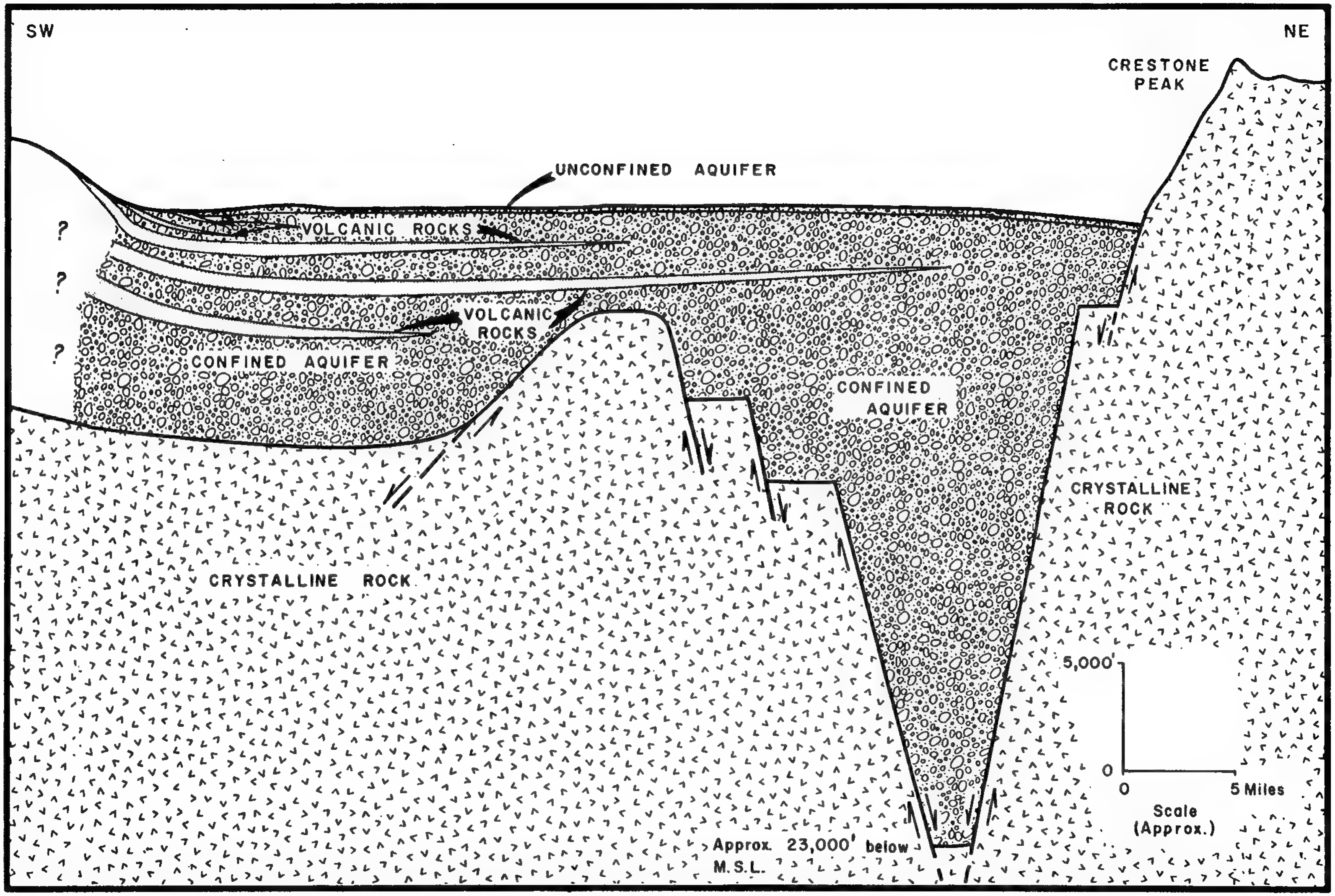

Figure 16. SW-NE cross section through San Luis Valley showing relationship between geologic conditions and aquifers (Modified from: Emery and others, 1969; and Gaca and Karig, 1966)

water above the clay layer occurs almost everywhere in the valley, with the depth to water in about one-half of the valley being less than 12 feet. Ground water in the lower confined aquifer is under artesian pressure. The quality of the water in the confined aquifer is generally better than that in the unconfined aquifer, with the concentrations of dissolved solids ranging from 70 to 437 mg/1. In the unconfined aquifer the concentrations range from 52 to 13,800 mg/1 with the least mineralized water occurring along the west side of the valley. Water with the greatest concentration of dissolved solids is found along the east side of the valley in the "sump" area just west of the Sand Dunes National Monument.

Ground-water withdrawals in the San Luis Valley during the period 1962-67, averaged 750,000 acre-feet per year. As stated before, more than 2 billion acre-feet of ground water are estimated to be stored in the deposits underlying the valley. This is a sufficient amount to supply current consuptive use for 1,000 years.

There are 5 large thermal springs located in the Rio Grande drainage basin. These springs have a combined annual discharge of 695 gallons per minute and add over 4,000 tons of dissolved solids annually to the waters of the basin.

WESTERN COLORADO

INTRODUCTION

Western Colorado, all that part of the state west of the Continental Divide, is characterized by high rugged mountain ranges and deep canyon lands and is drained by several major river systems. From north to south, they are: Yampa-White River, main stem of the Colorado River and its major tributaries: the Roaring Fork, Eagle River, Gunnison River and the Dolores River; and the San Juan River of southwestern Colorado (Fig. 17).

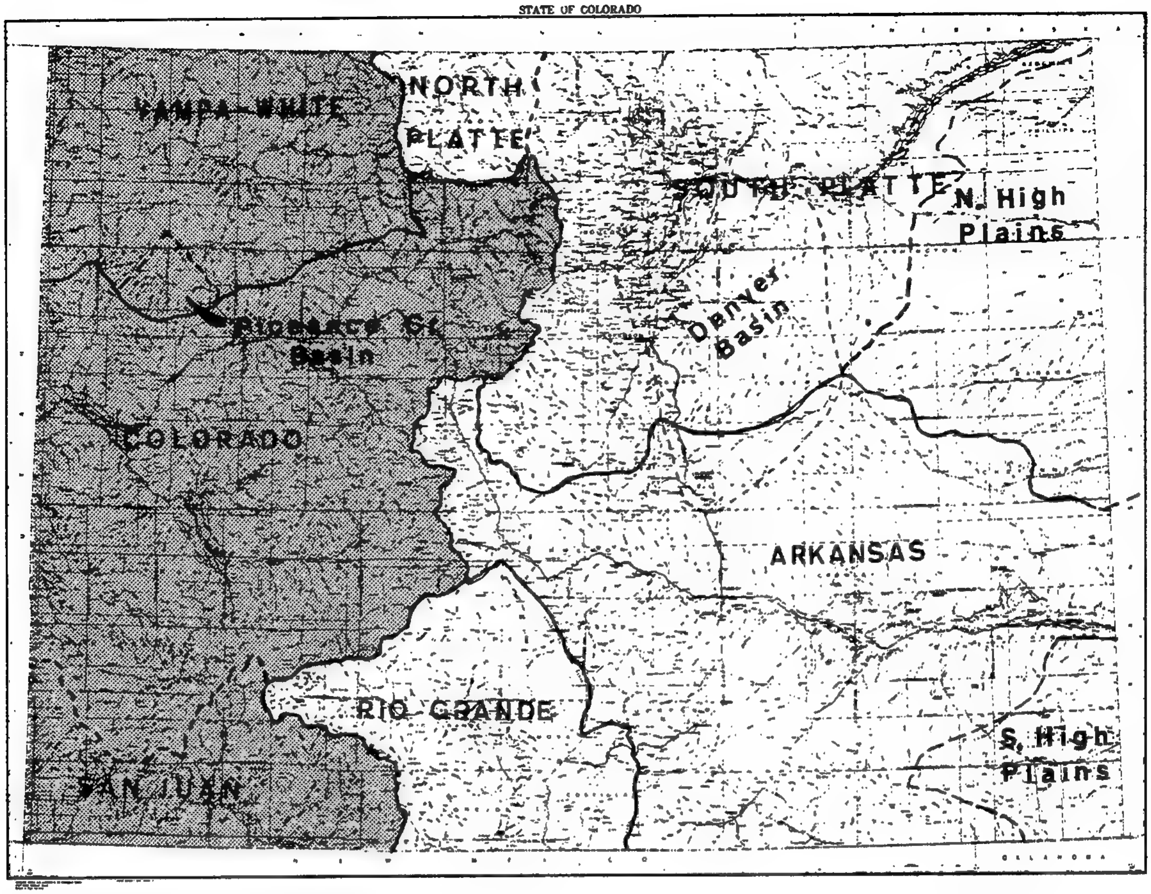

Figure 17. Western Colorado

Unlike that part of Colorado east of the Continental Divide, which has relatively abundant ground-water supplies, western Colorado has very limited quantities of available ground water (Fig: 5). It has been estimated that there are only 5-10 million acre-feet of recoverable ground water available in western Colorado. These available ground water supplies have not been greatly developed due to the topography and availability of large amounts of surface water. Consequently, the hydrogeological conditions of western Colorado have not been as thoroughly investigated as those of the eastern part of the State. As the geological and hydrogeological conditions are somewhat similar throughout western Colorado, no attempt will be made here to discuss those conditions by individual river drainage basins.

Table 6.— Summary of ground-water resources in western Colorado.

System	Formation	Thickness (feet)	Physical character	Water-Supply
Quaternary	Valley-fill deposits	20-140	Clay, sand, gravel, boulders, and glacial debris. Generally grades from coarse materials at the headwaters to finer materials downstream.	Principal source of water to large-capacity wells in the area. Yields as much as 1,000 gpm.
Quaternary	Colluvium, landslide debris, glacial moraines, terrace deposits	10-100	Silt, clay, sand, gravel, and debris piles.	Yields less than 20 gpm.
Tertiary	Volcanic rocks		Lava flows, breccias, tuff, and related materials.	Wells derive water from scoria zones, pores, and fractures. Source of water for domestic and stock supplies; generally yields less than 10 gpm.
Tertiary	North Park Formation	As thick as 1,500	Poorly sorted silt, clay, sand, and gravel. Contains lenses of sandstone and siltstone.	Source of water for stock and domestic wells; yields 700 gpm to one deep well.
Tertiary	Browns Park Formation	As thick as 1,800	Fine-grained grayish sandstone, gravel, cobbles, chert, fresh water limestone, and a conglomerate at the base.	Source of water for stock and domestic wells. May be a potential source of water for large-capacity wells. Locally water is highly alkaline.
Tertiary	Green River Formation	As thick as 3,500	Intertonguing lenses of siltstone, marlstone, sandstone, limestone, and shale.	Wells derive water largely from fractures and solution openings. Sandstone is relatively impermeable. Yields as much as 1,000 gpm.
Tertiary	Wasatch Formation	300-5,000	Clay, shale, and lenses of sandstone, limestone, and conglomerate.	Yields water to stock and domestic wells; reported to yield as much as 900 gpm to two irrigation wells.
Tertiary	Middle Park Formation	2,500-5,000	Sandstone, shale, conglomerate, and breccia.	Source of water to stock and domestic wells.
Cretaceous	Mesaverde Group	1,500-5,300	Mudstone, shale, coal, and varicolored crossbedded sandstone.	Source of water to many springs and large-capacity wells. Yields as much as 800 gpm.
Cretaceous	Mancos Shale 1000-5000 feet (West of Park and Sawatch Ranges). Pierre Shale	200-4,000	Dark shale and sandy shale with local stringers of sandstone.	Supplies water to stock and domestic wells locally where it contains fractures or weathered zones, but water generally highly mineralized. Not generally considered a source of water.
Cretaceous	Mancos Shale: Niobrara Formation	400-700	Calcareous shale and thin-bedded limestone interbedded with shale.	
Cretaceous	Mancos Shale: Benton Shale	200-600	Dark fissle shale with bentonitic seams and sandstone.	
Jurassic	Dakota Sandstone (Includes Burro Canyon Formation in southwestern Colo.)	As thick as 300	Light-colored sandstone, dark shale, and thin beds of coal.	Source of water to stock and domestic wells; yields as much as 40 gpm. Locally the water is saline.
Jurassic	Morrison Formation	250-600	Varicolored siltstone and mudstone with beds of sandstone and limestone.	Source of water to stock and domestic wells locally.
Jurassic	Curtis and Summerville Formations	50-200	Crossbedded sandstone, limestone, varicolored siltstone and mudstone.	Source of water for stock and domestic wells.
Jurassic	Entrada Sandstone	50-200	Fine-grained sandstone, mostly crossbedded.	Source of water for stock and domestic wells. Locally yields more than 25 gpm.
Triassic	Glen Canyon and Wingate Sandstones and older Triassic rocks.	As thick as 500	Sandstone, lenses of limestone, and varicolored siltstone and mudstone.	Sandstones are sources of water to stock and domestic wells.
Permian and Pennsyvanian	Permian and Pennsylvanian rocks	As thick as 13,000	Shale, limestone, dolomite, conglomerate, and sandstone.	Sandstone beds commonly yield saline water. Not generally considered a source of water to wells.
Mississippian	Leadville Limestone	50-200	Limestone, dolomite, sandstone, and chert.	Yields water from factures and solution openings. Yields as much as several thousands gpm locally. Extent of large yield potential is unknown.
Devonian Ordovician Cambrian	Pre-Mississippian rocks	As thick as 2,500	Dolomite, limestone, quartzite, sandstone, conglomerate, shale, and chert.	Yield small supplies of potable water at depths less than 2,000 feet.
Precambrian	Precambrian rocks		Granite, schist, gneiss, and pegmatite dikes.	Wells derive water from fractures and weathered material. Source of water for domestic and stock supplies; yields are generally less than 10 gpm.

Source of data: Colo. Water Resources Circular 15.

GEOLOGY

Precambrian age rocks, exposed in the central parts of the mountain uplifts consist of metamorphic schists and gneisses extensively intruded by granitic igneous rocks and quartzite. Overlying these rocks are sedimentary rocks of Paleozoic, Mesozoic and Cenozoic age with a net thickness of over 25,000 feet (Table 6). Nowhere in western Colorado is this total thickness of sedimentary rocks present in any one place.

The Cambrian to Mississippian age formations are primarily carbonates with some interbedded sandstones. The Upper Paleozoic Pennsylvanian and Permian Periods age formations consist of interbedded shales, sandstones, limestones and locally thick deposits of salt and gypsum. The Triassic and Jurassic (Lower to Middle Mesozoic) age formations are divided into a series of alternating sandstones and shale units. The Cretaceous age formations are divided into the Dakota group composed of sandstones and shales, the Mancos shale, and at the top, the Mesa Verde group consisting of sandstone, shale, and coal.

Rocks of Tertiary and Quaternary age, which are usually found in the central portions of the subbasins, are generally composed of continental sandstones, shales, coals, and locally abundant evaporite minerals. Overlying many of the above rock units, throughout large parts of western Colorado, are basaltic lava flows of Tertiary age. These flows have a total thickness of several thousand feet and are composed of several individual flows often separated by beds of volcanic ash.

HYDROGEOLOGICAL CONDITIONS

Some of the more important aquifers in western Colorado in descending order of age are: Valley fill alluvial deposits, Green River Formation, Mesaverde group; Dakota Sandstone; Entrada sandstone; Glen Canyon Group; Wingate sandstone; Leadville limestone; Pre-Mississippian age rocks and Precambrian crystalline rocks. With the exception of the valley fill deposits, the ability to tap any one of the above aquifers with a producing well is dependent upon several geological factors,

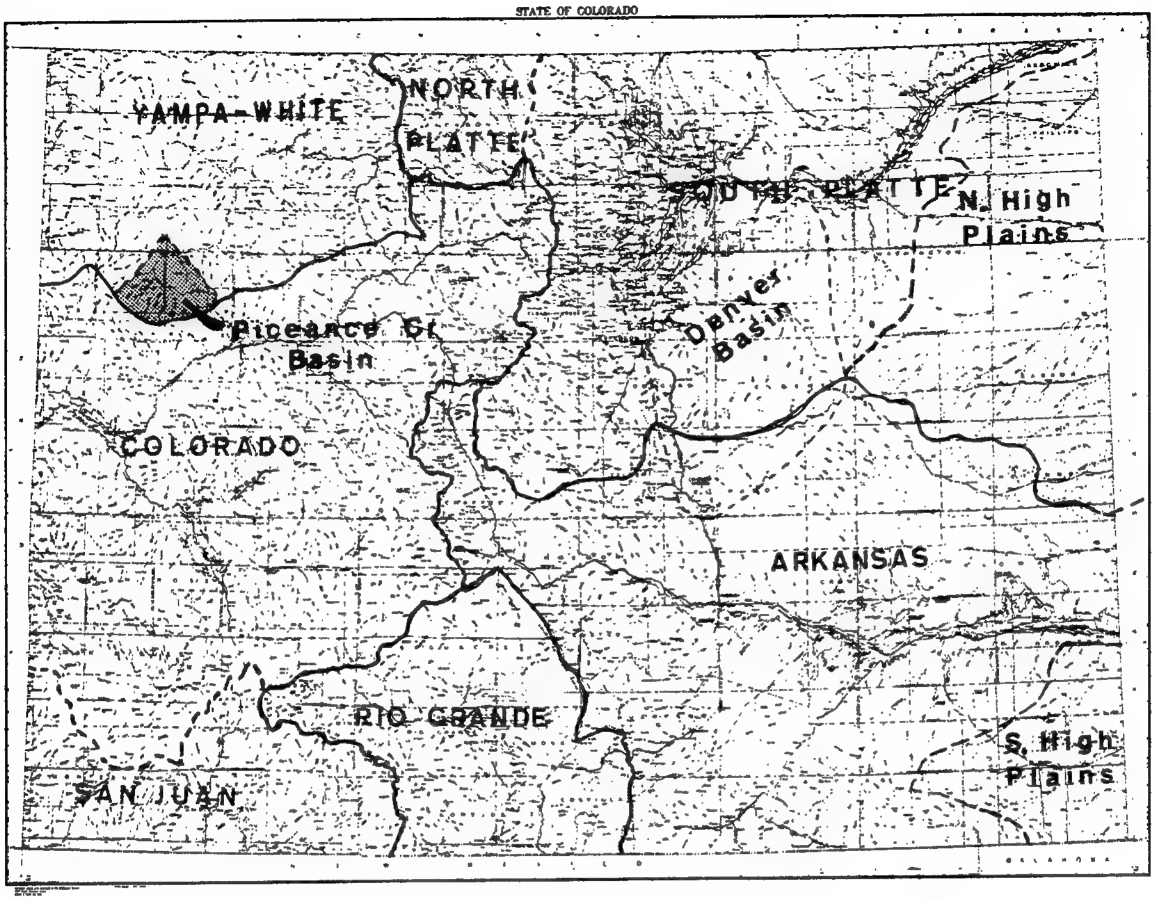

Figure 18. Piceance Creek structural basin

the most important of which is structure. Throughout much of western Colorado, the rocks have been complexly faulted and folded and directly affect the hydrogeologic conditions. These conditions are too complex to discuss on a local basis. For those interested in a particular area, they are referred to the various geologic maps published by the U.S. Geological Survey of specific areas in western Colorado. Due to the complexity of the geological conditions found in western Colorado, it is quite possible for ground-water to occur under artesian or flowing artesian conditions locally within the same aquifer.

Valley fill deposits are found to some extent along all the stream and river courses in western Colorado. These deposits, depending upon their extent and thickness, will yield from 5 to as much as 1,000 gallons per minute of water to wells.

That portion of the Green River Formation in the Piceance Creek basin which lies between the Colorado and White Rivers in northwestern Colorado (Fig. 18), contains as much as 25 million acre-feet of ground water. The water occurs in the interstices of the sandstone, in fractures, and in solution openings where sodium deposits have been leached by moving ground-water.

The Mesaverde group, composed of interbedded sandstone, sandy shales, and coal beds, is found throughout much of western Colorado. The group ranges in thickness from 1,500 feet to 5,300 feet. Some wells tapping this unit are reported to yield as much as 1,000 gallons per minute, but most well yields are less than 600 gallons per minute. Almost everywhere encountered, water from this unit will be under artesian pressure.

The Dakota sandstone, an important source of water for stock and domestic wells throughout much of western Colorado, yields moderate quantities of water to wells, usually less than 50 gallons per minute. The Dakota sandstone ranges up to 300 feet in thickness and consists of sandstone with some shale.

The Entrada, Glen Canyon, and Wingate sandstones, with a combined thickness of nearly 700 feet, yield small to moderate amounts of artesian water to wells in parts of western Colorado. Yields as high as 350 gallons per minute have been reported.

The Leadville limestone aquifer, which may be up to 200 feet in thickness, has been reported to yield as much as several thousands of gallons per minute of water to wells in parts of western Colorado. The water in the Leadville limestone occurs in fractures and solution openings.

The crystalline rock aquifers, like similar rocks elsewhere in Colorado, normally do not yield large quantities of water to wells--usually up to 10 gallons per minute. Where a well encounters large fault zones, larger yields may be expected.

The rocks in western Colorado are all soluble to some degree in water, with the quality of the ground-water resources being dependent

upon such factors as structure and rock types. The Precambrian age rocks and volcanic rocks of Tertiary age are generally the most resistent to the solvent action of water; consequently, the streams draining them have low concentrations of dissolved solids, usually less than 100 mg/l. The middle and lower reaches of the rivers are primarily underlain by sedimentary rocks such as limestones, sandstones, siltstones, shales and in some localities by formations containing evaporite minerals. As these rocks are more soluble than the metamorphic and igneous rocks, the dissolved-solid concentrations of the rivers increase progressively downstream with the waters containing large amounts of magnesium, sodium, sulfate, and chlorides.

A good example of how local geological conditions affect water quality is noted in four regions of the Colorado River basin. These four areas are: 1) The Eagle River valley, Eagle, Colorado to Glenwood Canyon. In this area, the Eagle Valley Evaporite Formation is exposed. This formation contains large amounts of readily soluble gypsum and other salts. While no data is available, it is believed that this section must contribute significant amounts of dissolved mineral matter to the river. 2) The second area is the Dolores River Valley, especially where the river crosses the Paradox, Gypsum and Sinbad valleys. These valleys are underlain by thick evaporite deposits; consequently, the river, after crossing them, has a high dissolved solid content. At times, the dissolved solids in the Dolores River at Cisco, Utah, just west of the Colorado-Utah border, reaches 6,000 mg/l with the water being a sodium chloride type. 3) Another area is the Grand Valley north and west of Grand Junction, Colorado. This valley, which is extensively irrigated, is underlain by the Mancos shale, which contains large amounts of readily soluble minerals. Primarily as a result of the effects of irrigation, 496,700 tons of dissolved solids are added annually to the Colorado River through this area. 4) The fourth area where the geological conditions have a direct effect on the quality of the surface waters in the Colorado River basin, is a part of the Piceance Creek structural basin where the Green River Formation

is exposed. This formation contains large quantities of water of varying quality. Water from the upper member of the Green River Formation is usually of good quality, while the water from the lower member is usually of poor quality, with dissolved solids as high as 63,000 mg/l. Ground-water discharge has a very deleterious effect on the quality of surface water in the Piceance Creek basin. For example, near the headwaters of Piceance Creek, the stream water is a predominately calcium, magnesium, bicarbonate type. At the mouth of the stream, the water is a sodium bicarbonate type and the total dissolved solids have increased from less than 600 mg/l. to 2,000 mg/l.

The single geological factor having the most impact on the quality of the water of western Colorado are the many mineral springs found throughout the area. With a combined discharge of almost 33,000 gallons per minute, these springs add over 528,000 tons of dissolved mineral matter annually to the rivers. The waters issuing from these springs are generally a sodium chloride type, but some of them may be a sodium bicarbonate or sulfate type.

SUMMARY

As has been noted, large quantities of ground water are found throughout Colorado. These ground-water supplies are a very valuable resource and will become even more so in years to come as the state continues to grow. In 1960, the last year of record, 16% of the total amount of water used for municipal purposes in Colorado came from ground-water supplies. During this same year ground-water supplies were utilized as the only source of water by 55% of the cities and towns in Colorado.

A substantial supply of ground water is available in most of Colorado, particularly in areas adjacent to the major streams, in areas underlain by extensive bedrock aquifers, such as the High Plains, and in some mountain areas. In the mountain and plateau regions of western Colorado, ground-water supplies are generally limited.

Large supplies of good quality ground-water are generally available in the alluvial fill, in the upper reaches of most river valleys, and in the High Plains of eastern Colorado. The alluvial fill in the lower reaches of the major river valleys generally contains a large amount of poorer quality ground-water. Waters from the most extensively used aquifers in Colorado are generally hard, having total dissolved solids greater than 121 mg/1. Ground water from the alluvium generally is hard to very hard. In consolidated aquifers, it is soft to very hard, with extreme variations found within the same aquifer.

While Colorado has abundant quantities of readily available ground water the occurrence of these supplies is quite variable. Geologically, Colorado can be divided into three distinct regions, in which the hydro-geological conditions are similar throughout: Plains on the east; high, rugged mountains in the center; and, canyon lands on the west. Found throughout these three areas are numerous structural basins containing thousands of feet of water-bearing rocks. Thus, the total amount of ground water in storage is extremely large-- well over 2 billion acre-feet in the San Luis Valley, and over 200 million acre-feet in the rest of the state. However, the amount of ground water in storage in any one region is strongly influenced by such geological factors as: degree of permeability of the material at the earth's surface; nature of the non-water-bearing formations; depth to the aquifer below the earth's surface; permeability of the aquifer; and, structural configuration of the aquifer.

Surprisingly, while much is known about the ground-water resources of Colorado and the geological conditions controlling their occurrence there is still great areas of the state, like the western slope, in which these conditions haven't yet been adequately appraised. Until these appraisals have been made on an adequate scale by either state, federal or consulting ground-water hydrologists, and the results published large amounts of this valuable resource will go unused.

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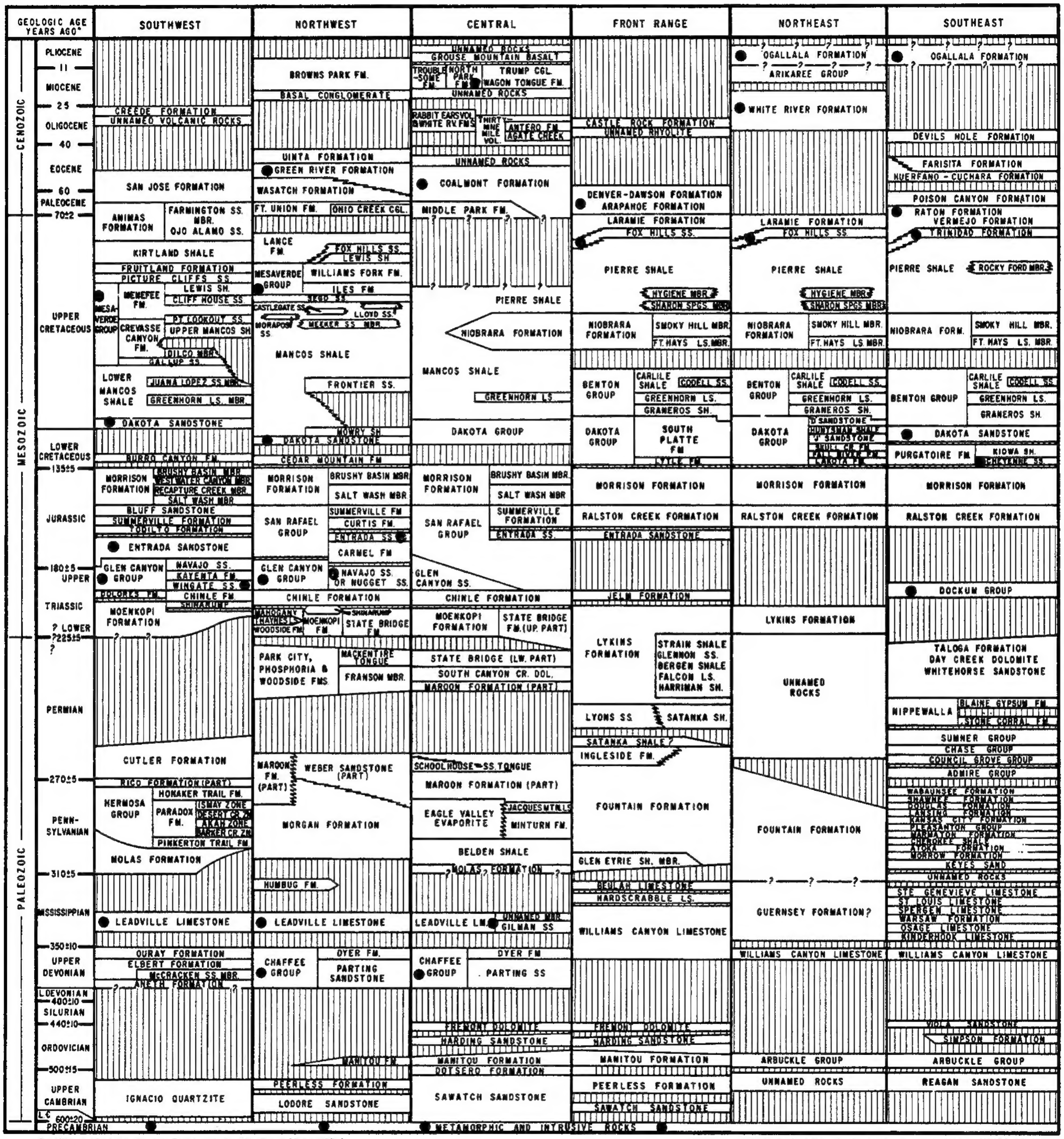
Table 7.

COLORADO STRATIGRAPHIC CORRELATION CHART

COLORADO GEOLOGICAL SURVEY



Compiled by: Richard Howard Pearl and D. Keith Murray (August 1974).
*Millions of years before present (Source: Geochron Laboratories, Inc.)

Source of data: Geologic Atlas of the Rocky Mountain Region (RMAG, 1972) and other publications. Reviewed by selected members of the RMAG.

● Principal aquifer